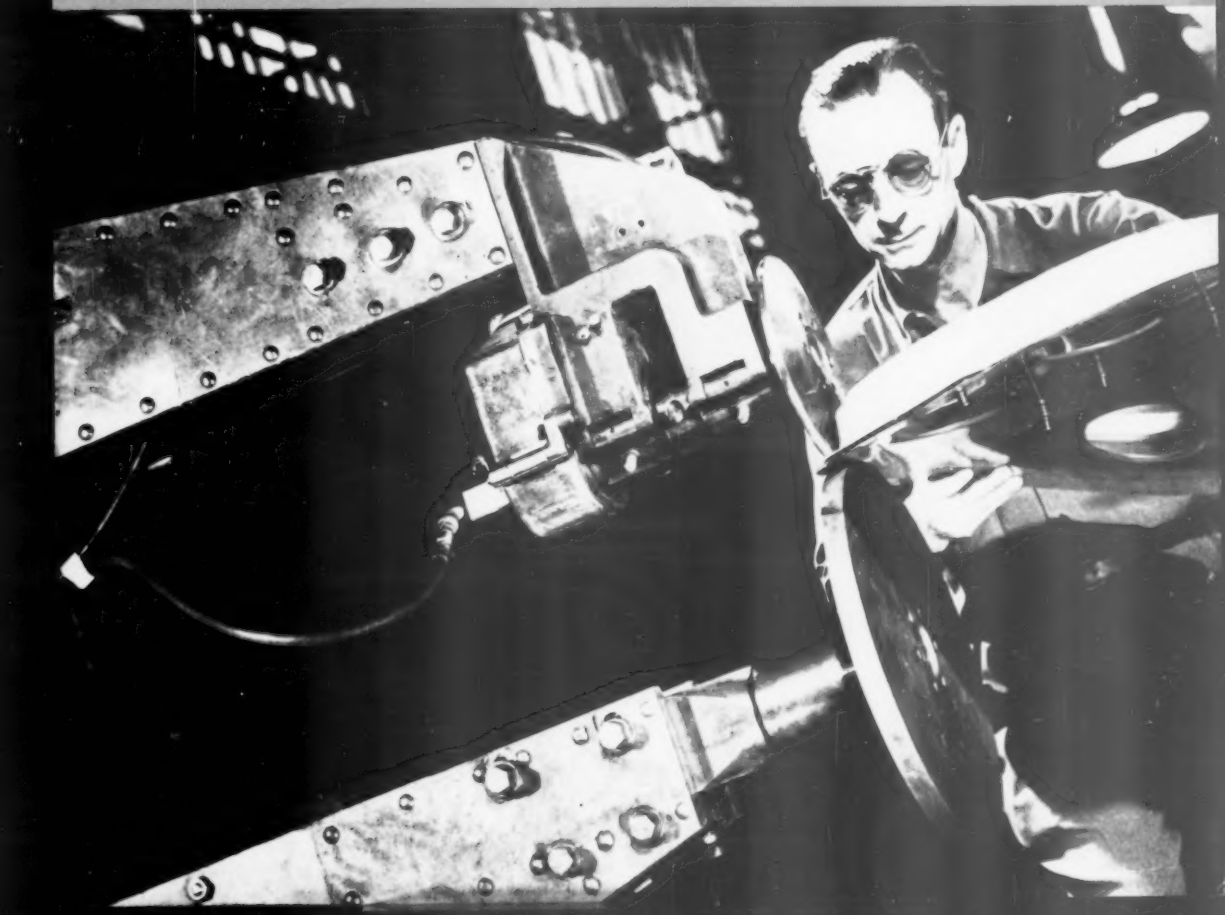
JUNE, 1949

The WELDING JOURNAL

Official Publication of the American Welding Society



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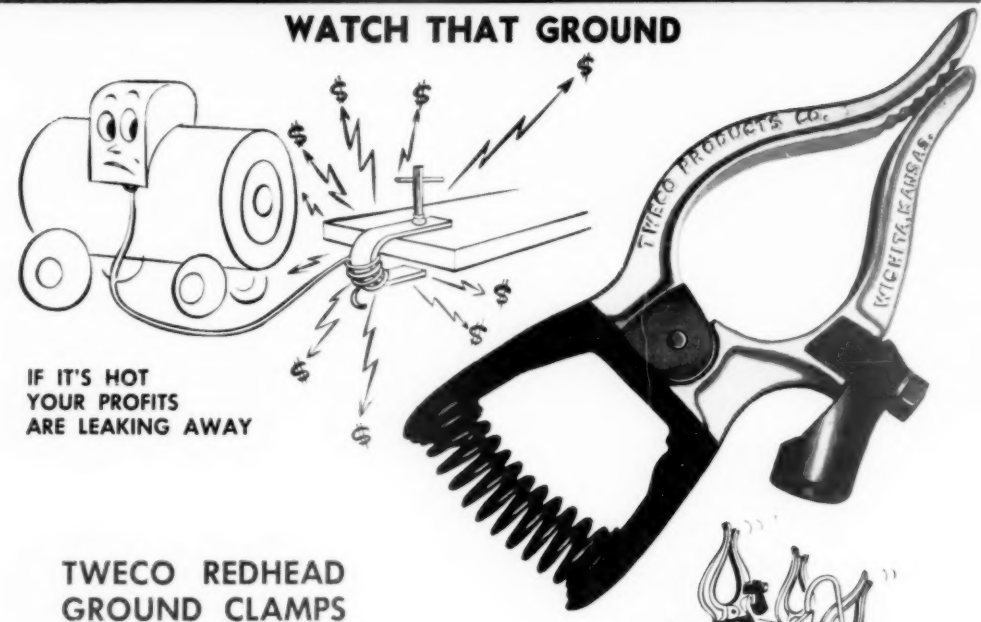

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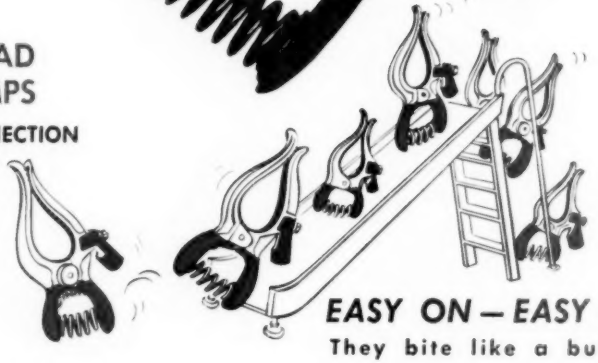

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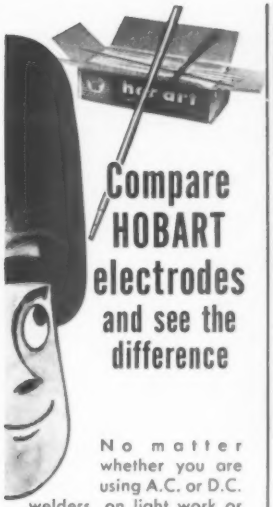

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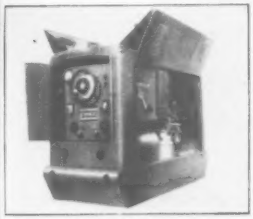

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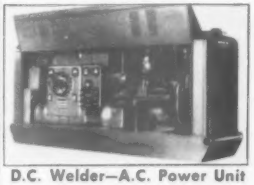

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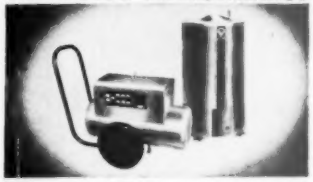

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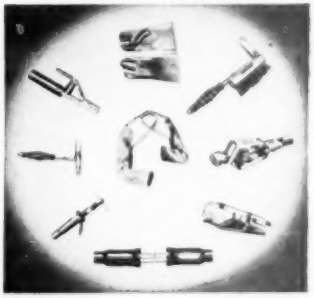

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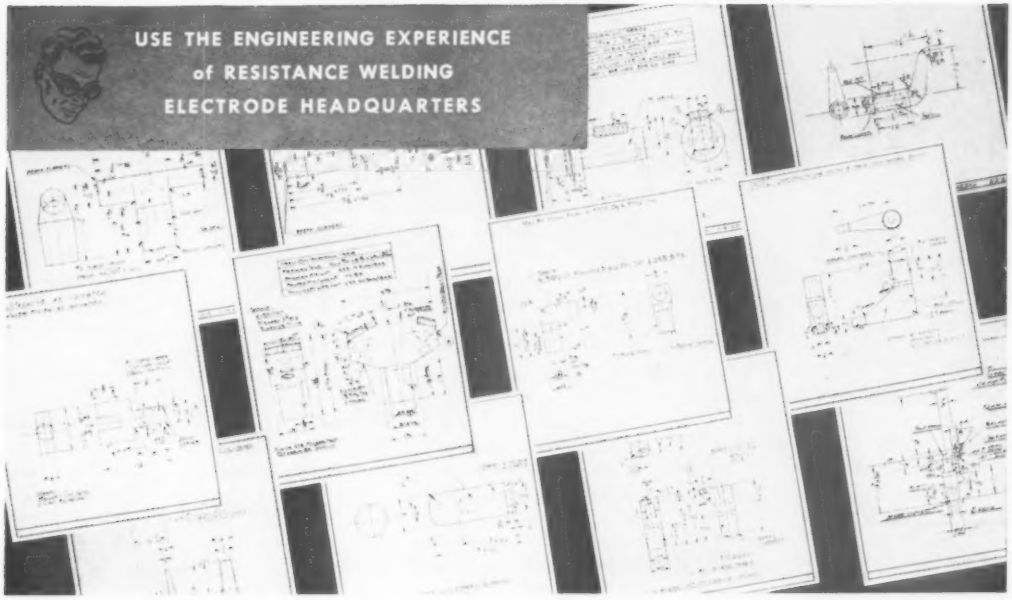

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The WELDING JOURNAL

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Development of Pressure-Vessel Codes

How codes are prepared, revised and interpreted. Safety must be balanced against economy. Some provisions of the A.P.I.-A.S.M.E. Code

by Elmer O. Bergman

A CODE is a system of principles, rules or regulations relating to a given subject. Codes are written to cover a variety of fields of work. We shall limit this discussion to codes for safe construction, and particularly to codes for the construction of unfired pressure vessels.

The definition of a code as a set of rules or regulations implies some sort of compulsion. This compulsion may be either legal or moral. The provisions of a code may be carried out either by legal enforcement or by voluntary agreement through contract or custom.

Just as we can consider government under the three divisions of the legislative, the executive and the judicial, so we can break down code activity into drawing up the code, enforcing it and interpreting it. The work of drawing up a code is done by its sponsor organization. The sponsors may represent one or more of the groups affected by the code, such as producers, users, insurers, material suppliers, government, contractors.

Examples are (1) The Electrical Safety Orders of the California Division of Industrial Safety, a government agency. (2) The Specification of the Design, Fabr cation and Construction of Structural Steel for Buildings of the American Institute of Steel Construction, a producer group. (3) The National Electrical Code of the National Fire Protection Association, a group largely directed by insurers.

The ideal sponsor organization should represent the various points of view of those concerned with the code. The code-writing group should strike a reasonable balance among producers, users and general-interest groups, and should give proper representation to industries and to geographical areas. Professional societies, such as the AMERICAN WELDING SOCIETY, are an ideal means for accomplishing this.

Code rules cannot go beyond the knowledge, experience and judgment of the group that writes them. A diversity in the interests of the group members and in the areas they represent will result in better rules than those from a group of narrower interest. Consider, if you will, the greater safety to personnel that an electrical code sponsored by a general-interest group would provide, compared with one sponsored by a group whose primary interest relates to fire protection.

Sponsor organizations are in general non-governmental agencies. To secure voluntary acceptance of a code under such sponsorship, there should be a real need for the code, it should embody the latest and best knowledge on its subject, and it should deal impartially with the different groups that it affects. Codes so sponsored are often adopted by regulatory bodies when they deem that voluntary acceptance does not accomplish the desired result. This cooperation between the sponsor organization and government promotes safety through each performing the part he is best fitted to do. The sponsor furnishes the technical knowledge of materials, design and fabrication that is needed to define a standard of safety. Government through its enforcement authority sees to it that everyone lives up to this standard.

An important concomitant of this cooperation between a national organization and governmental groups, is the establishment of a high degree of uniformity in the requirements of the different states and cities. This is an important consideration in an economy such as ours that is so largely dependent on mass production.

Our comparison of codes with government breaks down when we come to consider the judicial phase. We do not find a separate group charged with the work of interpreting codes. Interpretation is divided between the sponsor group that writes the rules and the regulatory group that enforces them. What is the

Elmer O. Bergman is with C. F. Braun & Co., Alhambra, Calif.

This paper was presented at the Western Metals Congress, April 11-15, 1949, Los Angeles, Calif.

basis for dividing the work between the two groups? As I see it, the principles of division are clear. One group deals in general terms, the other in particular applications. The sponsors who write the rules have the responsibility of saying just what the rules mean and of defining the limits of their application in general terms. If a rule is ambiguous, it is their duty to rewrite it in clear language. When and if technology develops new materials or new methods, the sponsors should make changes and additions in the rules to cover them.

It is common practice to revise codes periodically. The frequency of revision depends on the rate of technical development in the field and, we may assume, on the energy and interest of the code committee. Too few code groups have made adequate provision for handling interim interpretations and extensions of the rules. Happily more and more code groups are recognizing their obligation to provide machinery for answering the questions: What does this rule mean? What provision is made for this type of construction?

The regulatory body has the responsibility of judging whether a given rule applies to a particular case. Through its inspectors it answers the questions: Does this rule apply to this construction? Does this construction meet the requirements of this rule? This job of the inspector is a big job and an all-important job. To do it properly, he must have adequate rules, unambiguous rules to work from.

The purpose of a safety code is to provide a reasonable degree of protection for life and property from the hazards incident to the use of the constructions covered by the code. The code should strive for a balance between the degree of hazard and the probable nature and extent of damage, on the one hand, and the degree of safety that the public can afford to pay for on the other.

The old-world story my mother used to tell comes to mind in this connection. An old woman was loading wood on her cart. As she added stick after stick she kept saying to the horse, "If you can take that one, you can take this one. And if you can take that one, you can take this one," until she had piled on all that the cart would hold. What a fine load of wood she had. It would keep her warm for many a day. The only trouble was, that try as he might, the poor horse couldn't move an inch with the load.

Like the old woman, we can overlook the strength of the horse, and pile on rule after rule, each aimed at greater safety, till we have more than the economy can carry. The sequel of the story is equally instructive. Finding the load too great she started unloading. Now her refrain ran thus, "If you can't take that one, you can't take this one." No need to tell you the result. Neither is there any need to point out the difficulty of striking a reasonable middle ground, whether in loads of wood or in rules of safety.

Many codes recognize differences in hazard and probable damage. The A.S.A. Piping Code sets up use areas that are considered to have different degrees of hazard. The A.S.M.E. Boiler Code provides one set of rules for fired boilers and another for unfired pressure vessels. The A.W.S. Code for Arc and Gas Welding in Building Construction recognizes certain welding procedures that do not require qualification while others whose safety is not so well established have to be qualified. All this leads to the conclusion that codes are becoming more explicit, more selective, more exact. There is more knowledge and science, less of the earlier empiricism and extrapolation. This, of course, is just what we should expect.

Let us consider briefly how this development has taken place in the field of pressure vessels. Our knowledge concerning them is a development of the present century. Williams D. Halsey, in outlining the history of boilers at Boston last spring, told us that as late as the 1890's, "mysterious agency" theories of boiler failures still received widespread support.

The first edition of the Boiler Code was issued in 1915. The A.S.M.E. Unfired Pressure-Vessel Code celebrates its twenty-fifth anniversary this year. The first edition appeared as a modest booklet, 38 pages, including title page and materials specifications. The group that wrote it was largely from the boiler industry and, except for welding, the rules were largely a compilation from the Power Boiler Code.

Different groups approach a new field of knowledge from different directions. Each looks at the field from a different point of view and explores it in a different way. Each group systematizes the knowledge it gains, builds theories on it, bases rules on it. Such an approach to a subject tends to establish it on a broad base and has much to recommend it. If more than one group sponsors a code in the beginning, that need not be something to frown upon.

Such has been the history in the pressure-vessel field. The oil refinery industry is a pioneer user of pressure vessels. Their need for gas-tight vessels led to early development in the field of welding. New materials have been required to combat corrosion. Year by year we have seen larger and larger vessels, higher temperatures and higher pressures. A code to meet the needs of this industry was brought out in 1934. It was written by a group from the American Petroleum Institute, with A.S.M.E. joining in as co-sponsor. With its refinery and user origin, it differed in many respects from the A.S.M.E. Code with its predominant boiler and producer background.

The difference between these first codes was more in what they emphasized and what they omitted than in disagreement on the material that they had in common. The principal differences in this common material are in the factor of safety and in the way in which joint efficiency is handled.

Hard on the heels of the A.P.I.-A.S.M.E. Code came efforts to write a single code on which both groups could unite. With it has gone another equally important work, that of writing rules to cover phases not included in the earlier codes. Such rules, developed sometimes by one group, sometimes by the other, some-

times jointly, have mostly been adopted by both codes. This common adoption has greatly increased the number of rules that are the same in the two codes.

The special committee that was set up to revise the Unfired Pressure-Vessel Section of the A.S.M.E. Code has produced draft after draft. Public hearings on the revision have been held here in Los Angeles, in Houston, and in New York. The final draft is now being set up in galley proof. At the same time the A.P.I.-A.S.M.E. Code Committee has been working on a revision of that code.

The changes involved in these proposed revisions are too numerous to cover in detail. I shall limit myself to an enumeration of the more important ones. Before I mention any of them, may I add a word of caution. These rules have not yet been finally adopted. There may be some last-minute changes. Not many, but they may affect the particular rule that you may be most interested in.

Perhaps the most important change is the adoption of a common method of assigning joint efficiencies. The procedure followed by the A.P.I.-A.S.M.E. Code replaces that of Pars. U-68, U-69 and U-70 and the more recent U-200 and U-201. This gives greater flexibility in fitting the design to the needs and hazards of the intended service.

Of almost equal importance are the changes in the tables of maximum working stresses. The stress values up to 650° F. are based on a factor of safety of four. For structural grade steels, the stress is further reduced by the application of a quality factor. We may look further for the elimination of the difference between the stress values at the higher temperatures that now separate the two codes.

A third point of difference has been the test pressure. This is now on the way to being standardized at $1^1/_2$ times the allowable working pressure. The A.S.M.E. has already taken a step in this direction by the adoption of Case 1087, permitting test pressures of $1^1/_2$ times the working pressure for all types of power boilers.

Differences between the codes in the rules for fabrication and inspection have long been the bane of fabricators and inspectors. The A.P.I.-A.S.M.E. rules were written later and on the whole have wider coverage and clearer expression. The New Section VIII adopts them for the most part. What changes are made are usually to make the rules still clearer.

The rules for figuring reinforcement of openings are revised to agree quite closely with the present A.P.I.-A.S.M.E. rules. Rules are added to cover the design of dished heads. These follow Case 997. Both codes adopt rules for applying quality factors to castings based on Case 986. Both propose changes in the rules governing pressure-relieving devices. Both will have procedures for identifying unmarked materials. A rule that should be acceptable to all has been worked out to provide for inspectors in the employ of users. It was written by a committee of nine representing the A.P.I., the A.S.M.E. and the National Board.

A.P.I.-A.S.M.E. are studying changes to bring that code in close agreement with the New Section VIII. These include adoption of the rules on low-temperature and those on high-alloy material, in addition to those already mentioned.

What is the effect of this approach to uniformity in the two codes? What are the chances for agreement on a single code? If I were called on to make a prediction, I would say that the chances are good. My prediction would be based on the way codes in other fields have developed.

Earlier, I mentioned the tendency to bring out more than one code in the early stages of development. Such early codes are fragmentary. There is not too much overlapping coverage. The material common to these codes increases with increasing knowledge and experience, until finally the difference settles down to one approaching Tweedledum and Tweedledee.

When such a time arrives, the immense advantage of a common code makes itself felt. The great body of users are not impressed by arguments over minor points of disagreement. Settle your differences, they say, and give us a single code with which to work.

The A.I.S.C. Specification for the Design, Fabrication and Construction of Structural Steel and the A.W.S. Standard Qualification Procedure, to name but two, are examples of the acceptance of a well-developed code as a universal standard. All the comments I have heard on the New Section VIII confirm my belief that it too is destined to gain universal acceptance.

WELDING METALLURGY

The internationally known book on the above subject originally written by Henry & Claussen has been completely revised, enlarged and brought up to date by G. E. Linnert. A book of 505 pages, handsomely bound, price $2.50. Order your copy now! American Welding Society

Sound Welding

A brief interpretive outline of the standardization and code activities of the Society and how such activities may be utilized in specifying and securing good welding

by Simon A. Greenberg

WHETHER welding was known to the ancient Egyptians, as is claimed by some, or whether its first use was in the blacksmith's shop of the horse and buggy days, none of these earlier practitioners would associate the welding practices of industry today with the crude methods known in those early days.

So great are the changes and so numerous have been the developments of the past few years that even the industrial applications of welding during World War I, when welding was first used to any significant extent in the United States, now are outmoded almost to the extent of being purely of historic interest.

It was because these earlier users of welding recognized how much development there would be, and how the applications of welding would grow and expand to different fields, that they grouped together in 1919 and organized what has become the AMERICAN WELDING SOCIETY.

During World War I, The Emergency Fleet Corporation established a group of engineers to plan the use of welding in a national shipbuilding program—always vital in wartime. With the end of the war, these engineers sought to establish a channel through which information on new applications of existing methods, and developments of new methods and processes relating to welding could be widely disseminated. There was also a need for a common meeting place for the welding-minded to get together and exchange ideas and experiences.

The history of welding since that time is the history of the AMERICAN WELDING SOCIETY. The increased recognition of welding as a sound joining method is reflected in the increase in the AMERICAN WELDING SOCIETY's membership and activities. A review of the membership and activities today would show that every principal industry in the United States is represented.

No single phase of the SOCIETY's activities better reflects the widespread use of welding than what we generally call the "Technical Activities" or "Standardization Activities."

These technical activities comprise the preparation of standards generally in the form of codes, specifications and recommended practices and the dissemination of these standards so as to be of the greatest assistance in accordance with the aim of the SOCIETY to promote the sound use of welding.

The welding standards of the SOCIETY serve three purposes. They serve to effect the standardization of materials and practices in industry, as a basis of regulatory provisions and as a source of general information.

The desirability of voluntary standardization of materials and practices by industry is too well recognized to require much further comment. It provides assurance of uniformly good quality under diversified fabricating conditions, or, in the case of materials, it permits the fabrication of a product using predetermined procedures according to the known characteristics of the materials involved and a ready interchange of materials such as welding rods and electrodes and equipment such as arc welders.

Since the AMERICAN WELDING SOCIETY is not a regulatory body its standards are mandatory only when adopted by enforcing agencies. The adoption of these standards for administrative purposes has been promoted since they assure sound welding yet avoid the adoption of unduly prohibitive requirements. As an example, the *Standard Code for Arc and Gas Welding in Building Construction* is the basis for the welding requirements found in the municipal administrative code of every principal municipality in the United States, as well as the principal State Building Codes and the standard codes of building official's organizations such as the Pacific Coast Building Officials' Conference and the Southern Building Codes Congress.

By the nature of the information contained in recognized standards they are, of course, a source of good information on recognized practices and materials and thus have an educational value. To supplement the requirements of our standards and to provide information which does not properly belong in a standard, yet is helpful in the use of the standard, a policy has recently been adopted whereby an appendix is added to

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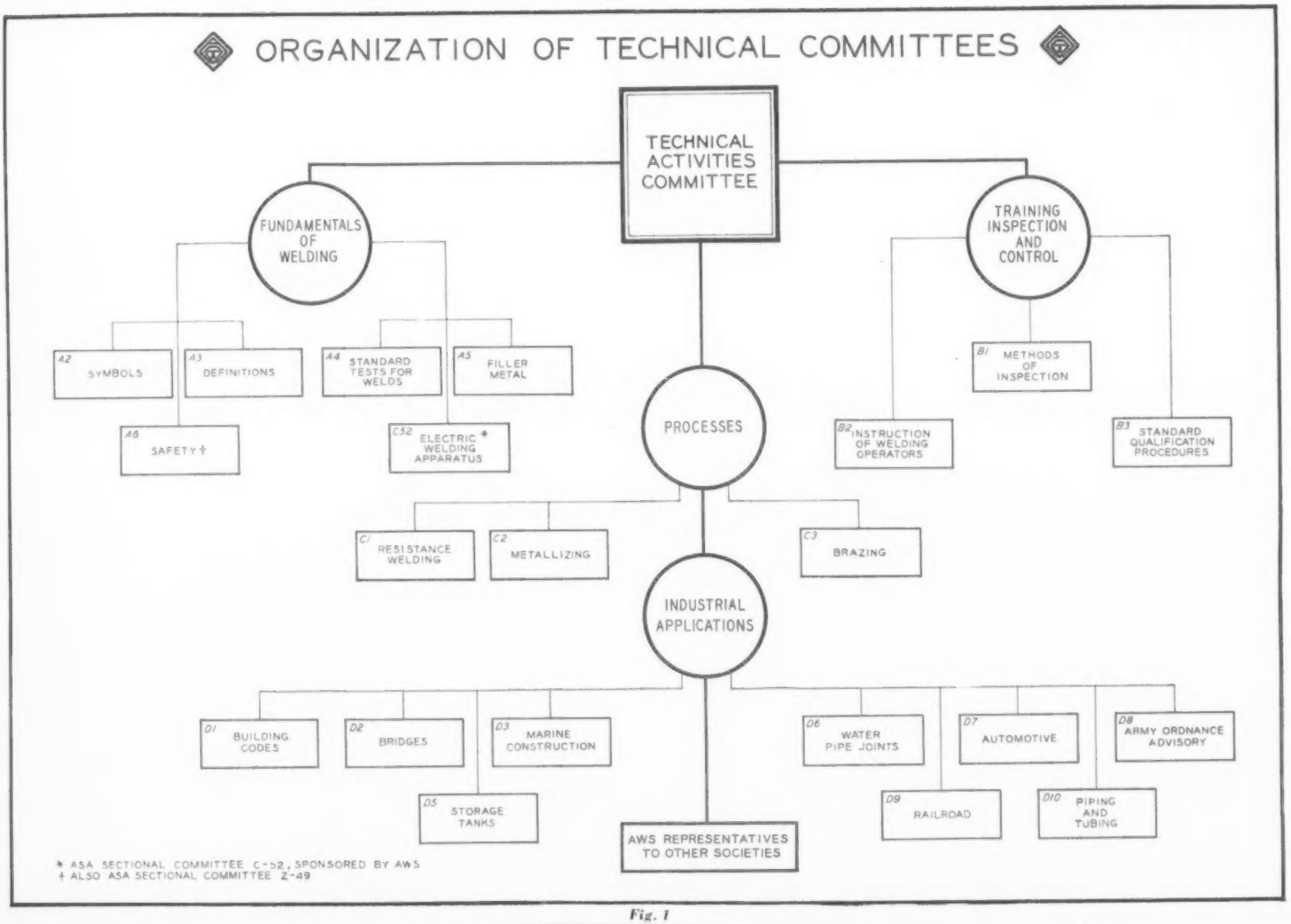
ORGANIZATION OF TECHNICAL COMMITTEES
TECHNICAL ACTIVITIES COMMITTEE
FUNDAMENTALS OF WELDING
TRAINING INSPECTION AND CONTROL
PROCESSES
INDUSTRIAL APPLICATIONS
A2 SYMBOLS
A3 DEFINITIONS
A4 STANDARD TESTS FOR WELDS
A5 FILLER METAL
A6 SAFETY †
C52 ELECTRIC * WELDING APPARATUS
B1 METHODS OF INSPECTION
B2 INSTRUCTION OF WELDING OPERATORS
B3 STANDARD QUALIFICATION PROCEDURES
C1 RESISTANCE WELDING
C2 METALLIZING
C3 BRAZING
D1 BUILDING CODES
D2 BRIDGES
D3 MARINE CONSTRUCTION
D5 STORAGE TANKS
D6 WATER PIPE JOINTS
D7 AUTOMOTIVE
D8 ARMY ORDNANCE ADVISORY
D9 RAILROAD
D10 PIPING AND TUBING
AWS REPRESENTATIVES TO OTHER SOCIETIES
* ASA SECTIONAL COMMITTEE C-52, SPONSORED BY AWS
† ALSO ASA SECTIONAL COMMITTEE Z-49

Fig. 1

each standard issued, either giving more detailed practical information as in the Filler Metal Specifications or explaining the philosophy and intent of new provisions. This has proved extremely helpful and should be considered for adoption by other organizations.

Where experience has shown that a subject requires very expanded treatment, attempt has been made to have a book written on the subject. Although formerly such books have been of a fundamental nature, as *Welding Metallurgy*, the SOCIETY is now planning to publish books relating to specific applications. The first of this type is *Practical Design of Welded Steel Structures*, which contains typical structural details and discussions on practical interpretations of the *Standard Code for Arc and Gas Welding in Building Construction*.

Preparation of each standard is by a technical committee comprising representatives from industry, balanced within reason among producers and consumers and selected so that all interests in the particular committee's activities will have proper representation. Incident to their operation the technical committees provide an opportunity for their members to exchange ideas and experiences as well as to discuss questions of mutual interest. With membership of technical committees being geographically disposed over the United States, this makes it possible for members in one area to find out what others in some of the other areas are doing in similar fabrications. In some degree, this has created uniform practices by common understanding and without written standards.

One of the best criteria for measuring the transition of the welding industry is the growth in the size, scope and number of technical committees since the SOCIETY's organization. The number and nature of these committees have been changed to keep pace with industrial requirements. New committees are organized after careful investigation shows that a real need exists, not otherwise filled by existing committees.

The most common basis for judging the need for a new committee has been the requests for its organization from industry itself. Thus the AMERICAN WELDING SOCIETY's Committee on Welding in Marine Construction was organized when the shipbuilding industry found that an increased use of welding in the fabrication of ships made it desirable to standardize practices and to provide for the exchange and correlation of information among the shipbuilders, shipowners and the regulatory bodies including the U. S. Navy, American Bureau of Shipping, the U. S. Coast Guard and the U. S. Maritime Commission. Similarly when authoritative information on the application of welding in structural steel fabrication was needed for guidance of building officials as well as designers and fabricators, the Committee on Building Codes was organized.

In the early stages, standardization was for the most part conducted on the basis of applications. It became evident, as welding was used by more industries, that need existed for standards in basic matters common to all applications. Committees were then organized to formulate standards on welding nomenclature and definitions, symbols, filler metal, safe practices and training and qualifying welding operators.

The expansion of the AMERICAN WELDING SOCIETY's technical committees has continued so that today they number twenty-two as shown in Fig. 1. In addition the single block, "A.W.S. Representatives to Other Societies," at the bottom of the chart includes more than twenty individual representatives on technical committees of such organizations as the American Standards Association, American Society for Testing Materials, American Transit Association, Association of American Railroads, American Institute of Electrical Engineers and Heating, Piping and Air Conditioning Contractors National Association, as well as many others. These A.W.S. representatives provide the cooperation of the SOCIETY in standardization activities within particular industries in which welding is only one aspect of the over-all standardization program. Committees, subcommittees and special groups number over 100 and their membership includes over 400 industrial leaders from every field and every location.

It will be noted from the chart in Fig. 1 that the Committees are grouped in four major categories, all under the jurisdiction of the Technical Activities Committee. This committee comprises the Chairmen of all the individual technical committees with not more than three members-at-large serving by appointment of the president of the SOCIETY. The Technical Activities Committee, which has jurisdiction over all of the standards activities, is the administrative body to which the Board of Directors looks for recommendations on these activities. Close correlation of all technical activities is effected through the staff at headquarters under the Technical Secretary, who also serves as Secretary of the Technical Activities Committee.

Referring again to Fig. 1, it will be noted that all of the committees whose activities relate to such basic matters as definitions, symbols, safe practices and filler metal are grouped under the heading "Fundamentals of Welding." Similarly, the committees whose activities relate to testing, qualification requirements and training of welding operators and qualification of welding procedures are grouped under the heading "Training, Inspection and Control." For the most part the activities of the committees in these two categories relate to all of the welding processes in use today, of which there are about thirty-seven.

Standardization activities for several of the welding processes have not been developed to the same extent as the others. This is due in part to their later development and in part to their more recent application on a wide industry basis. Individual committees have been organized for concentrated activities on these processes.

Each of the committees shown in Fig. 1 under the heading "Processes" is organized to include subcommittees covering the more fundamental aspects coming within the scope of activities of the committees grouped

under the first two headings. The work of each "Process Committee" is correlated with the work of the appropriate "Fundamental Committee" or "Inspection Committee" and it is planned to ultimately disband these "Process Committees" when their activities can be assimilated according to basic subjects as definitions, qualification, etc.

While metallizing is not a welding process, the Metallizing Committee was organized a few years ago when many requests were received indicating the need for standardization and suggesting that the AMERICAN WELDING SOCIETY was the logical body for such activity because much of the equipment used was the same as for welding and because no other organization existed which included activities on metallizing. Then too, investigation showed that in many plants it was common practice to assign the responsibility for metallizing applications to the Welding Engineer and his department, probably because of the similarity in equipment noted above.

The last grouping of committees is headed "Industrial Applications." Each is concerned with the promulgation of standard requirements for welding as applied in the industry indicated by its name, and in related industries. Each of these committees comprises persons from a particular industry on the basis of geographic representation and, usually, although not always, on the basis of representation from the user, producer and material and equipment suppliers.

Generally, these "Industrial Committees" make the necessary adaptation of the more basic and general standards prepared by the technical committees grouped under the other headings, for the use of welding in their particular industry. The standards of these committees may be in the form of recommended practices as the *Recommended Practices for Automotive Flash-Butt Welding* or in the form of mandatory requirements intended for adoption by regulatory bodies as in the case of the *Standard Code for Arc and Gas Welding in Building Construction*, or in the form of specifications, which serve as the basis of construction by mutual agreement between purchaser and supplier as in the case of the *Specifications for Welded Highway and Railway Bridges*.

The *Recommended Practices for Automotive Flash-Butt Welding* are an adaptation of the fundamental flash-butt welding standards of the more basic *Recommended Practices for Resistance Welding* supplemented by rules on design, equipment, technique and inspection particularly applicable to automotive fabrication.

The *Standard Code for Arc and Gas Welding in Building Construction* and the *Specifications for Welded Highway and Railway Bridges* include basic requirements for filler metal, workmanship and inspection methods adapted for these particular applications with design requirements established specifically for those types of construction by research and investigation. Both of these standards contain identical requirements except where modification is necessary to properly provide for the incidence of repetitious dynamic loads producing maximum stresses in bridge members.

Each technical committee has been organized on a broad basis to provide for the necessary expansion or modifications of its scope of activities according to the needs of industry without too much formality and regulation. Thus each committee functions in a flexible manner expanding, reducing or even modifying its activities to some extent as indicated by the standardization needs at any given period.

A very good example of this is the Committee on Filler Metal. When first organized more than twenty-five years ago, this committee prepared a standard for plain, bare steel wire of specified chemical analysis and size, merely "to exclude the use of fence wire" for welding. This is representative of the state of welding at that time. Today, with thirty-seven welding processes in use, this same committee, now jointly sponsored by the AMERICAN WELDING SOCIETY and the American Society for Testing Materials, has a membership of almost seventy and carries on its activities through nine subcommittees working on specifications for electrodes, welding rods and brazing materials for all of the ferrous and nonferrous metals being welded today.

To cite one more example, the Committee on Building Codes prepared its first standard on the welding of structural steel in 1928. This was a four-page booklet containing general requirements according to the limited experience up to that time. Today, the 1946 edition of the *Standard Code for Arc and Gas Welding in Building Construction* comprises a complete and detailed set of regulatory provisions covering material, design, workmanship and inspection. This standard has gained in recognition the past twenty years until today it forms the basis of administrative requirements for welding in the building codes of practically every municipality in the United States.

With the "one-world concept" gaining more followers every day, and with the airplane making distances shorter and bringing remote areas nearer and nearer to each other, international standardization is a matter of much consideration today. In this connection the SOCIETY has established a regular exchange between welding organizations and other bodies standardizing on welding throughout the world. Contact and an exchange of publications and information has been effected with organizations in Canada, England, France, Belgium, Holland, Australia, New Zealand and Switzerland among other countries.

This activity is not directed toward effecting universal standards on materials, equipment or procedures. It does, however, provide a basis for agreement on fundamentals and where it is practical and desirable voluntary adoption of American standards by foreign countries and vice versa is abetted by mutual cooperation and very friendly relations.

That these standardization activities of the AMERICAN WELDING SOCIETY have been of value will not be disputed. The excellent cooperation of industry, without which such activities are impossible, and the general

adoption of AMERICAN WELDING SOCIETY standards by federal, state, city and industrial regulatory bodies as well as their use in individual contracts is the best evidence of the value they have served. Therefore the few examples of the results of the AMERICAN WELDING SOCIETY's standardization activities are cited here not as evidence but because of the interest they may have as a matter of information.

It has always been recognized that welding operators should be required to demonstrate their ability to weld before being permitted to work on important fabrication where the safety of people or property would be involved. In the beginning, in the absence of uniform standards for such qualification, each industry imposed its own qualification tests on the welding operator, and in many instances the test requirements varied from one manufacturer to another within the same industry. In general, it was a matter of diverse, individual ideas. All of the tests, however, attempted to simulate actual production conditions for the welding of the operator's test plates. The required tests provided for the determination by one means or another of the mechanical properties of the welded joint as well as its soundness. A welding operator could be incapable of passing a test because of the faulty procedure prescribed or because of his lack of ability; the tests made no distinction.

When the AMERICAN WELDING SOCIETY undertook to standardize qualification requirements for welding operators, the first step was to clarify the intent of such tests. It was established that the welding operator's ability should be demonstrated in his deposition of a sound weld. Such properties of the welded joint as its tensile strength or ductility were improved or reduced by the joint welding procedure prescribed. If the procedure were properly established, it remained for the operator only to be able to make a sound weld. Accordingly the standard test adopted for operator qualification examined only the soundness of the welded joint. At the same time agreement was reached as to an adequate, but simple, test for this purpose which was accepted as satisfactory for almost all types of fabrication whether buildings, bridges, railroad cars or pressure vessels. The *Standard Qualification Procedure* incorporating these concepts is now almost universally accepted and has been adopted in such standard codes as the Boiler Code, the Code for Pressure Piping, the Code for Unfired Pressure Vessels for Petroleum Liquids and Gases, the Standard Specifications for Elevated Steel Water Tanks, Standpipes and Reservoirs and many others.

Another example of simplification in industrial practices through standardization is welding symbols.

In the early days the selection of a welding process or welding procedure as well as the joint design and other such factors was left almost entirely to the welding supervisor or even the welding operator. It was customary for the designer to indicate where welding was required by a general note such as "Weld Securely" without any consideration of the particular properties required for the service conditions of the completed weldment.

However, as research established welding on an engineering basis and as welding became used for the fabrication of structures for more critical service conditions, whose safety might affect life and property, the design of welded structures was taken out of the hands of the shop personnel and transferred to the designer, where responsibility for design properly belonged.

This made it necessary for the designer to have a convenient means for conveying the required information to the shop in such a manner that it would be readily understood. The alternative to a lengthy description and detailed sketches for each joint was standard welding symbols.

The *Standard Welding Symbols* of the AMERICAN WELDING SOCIETY have filled this need very well. By their general acceptance through industry it is possible for a designer to indicate on a drawing the type of weld and joint as well as the details of welding for each joint in a structure, with assurance that a shop located anywhere in the United States will be able to interpret the information shown by the symbols and required welding performed. It is quite common to see wall charts containing a summary of these standard symbols on the walls of drafting rooms and welding shops.

The uniformity of requirements obtained by common standards as briefly described in this paper, by assuring the use of sound welding, has served industry in providing safer and more useful products for the advantage of the entire population.

The Laboratory in Resistance Welding

The resistance research laboratory must cope with problems involving applications ranging from phonograph needles to heavy structural plates and involving metallurgical, radiographic and chemical examinations

by F. R. Hensel and E. F. Holt

I. INTRODUCTION

THE Resistance Welding Division of P. R. Mallory & Co. is devoted to the manufacture and sale of electrodes and electrode materials, electrode holders, welding fixtures, dies and various other accessories for resistance-welding applications.

The Company maintains a Resistance Welding Laboratory, the primary purpose of which is to support the Resistance Welding Division in many ways such as:

1. Development and testing of new or improved resistance-welding products for manufacture and sale.
2. To furnish technical information relative to the design and weldability of customer's assemblies.
3. To establish, by test, suitable procedures and welding conditions for resistance-welding assemblies submitted by customers.
4. Conduct investigations and tests to determine the most suitable electrode materials and designs for various resistance-welding applications.
5. Develop, compile and publish technical literature on resistance welding.

In addition, the Resistance Welding Laboratory furnishes consulting and welding services to all other Mallory divisions, such as the Electrical Contact, Electronic Parts, Rectifiers, Special Products, Vibrator, Condenser and Battery. To illustrate the role of the laboratory in resistance welding, some typical examples of its functions have been selected and are herewith presented.

F. R. Hensel and **E. F. Holt** are Vice-President in Charge of Engineering and Chief Engineer of the Resistance Welding Division, respectively, with P. R. Mallory & Co., Inc., Indianapolis, Ind.

This paper consists of abstracts from a lecture given before the A.W.S. Northern New York Section, Nov. 18, 1948.

II. LABORATORY TESTS ON RESISTANCE-WELDING ELECTRODE MATERIALS AND DESIGNS

The performance of new or improved electrode materials and designs are evaluated by comparative life tests. The test conditions, such as the material welded, equipment and welding conditions, are selected as representative of typical production welding practices.

Prime care is exercised in measuring and controlling all variables likely to influence the performance of the electrodes or the significance of the test results. One of the factors measured and controlled during performance tests is the welder sequencing. Generally, motor-operated press-type resistance welders are preferred for running electrode performance tests primarily because once the sequencing is set, it will be maintained since the driving motor operates in synchronism with the frequency of the power supply. The "push-up" on the welder head is kept at a predetermined value, and since the motor driven movable head of the welder operates at a constant average velocity, the impact force on the electrode will be reasonably constant. The adjustment and measurement of the welder sequencing is made prior to a test run and is checked periodically during the run.

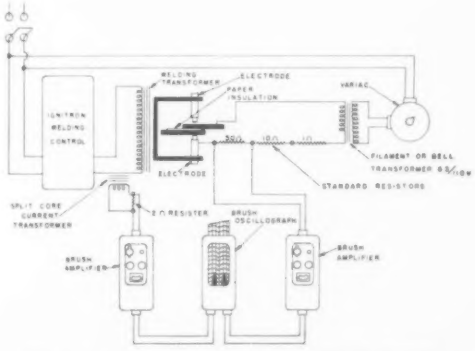

Fig. 1 Circuit diagram for determination of welder sequencing

A relatively simple electrical circuit used for the determination of squeeze time, weld time, hold time and off time is shown schematically in Fig. 1. The welder speed is adjusted to a predetermined number of strokes per minute and the "push-up" (which supplies the force on the electrodes) adjusted with the material to be welded between the electrodes. A thin piece of paper is placed between the materials to be welded which insulates the top material. When the welder is operated automatically, the upper electrode, in making contact with the top sheet, completes the electrical low-voltage measuring circuit and the current flowing through the standard resistor causes a voltage drop which is impressed on the Brush amplifier. The amplified voltage drop is in turn impressed on the Brush direct inking oscillograph, initiating a 60-cycle trace on the oscillograph tape.

When the weld timer is initiated by the action of a limit switch on the welder, an additional voltage (the welder secondary voltage) is impressed on the measuring circuit in time-phase with the measuring circuit voltage. The welder voltage is either additive or subtractive to the measuring circuit voltage depending on its polarity and results in a trace on the oscillograph either greater or lesser in magnitude than the measuring circuit trace. When the weld timer ceases firing (removing welder secondary voltage), the oscillograph trace returns to its initial value.

The rate of rise in applied force is extremely rapid in an air cushion head type, motor-operated welder, providing the electrodes are mounted rigidly and excessive deflection of the welder members is avoided. This is because the air pressure in the welder head is maintained at its steady state maximum.

The duration of the welding current is determined periodically during the test with the arrangement also shown in Fig. 1, in which a signal is obtained from a split core current transformer and a voltage across a low resistor is impressed on the Brush amplifier, producing a 60-cycle trace on the oscillograph.

The complete oscillographic trace of the welder operation is represented by Fig. 2 and the various elements of the welder sequencing are measured from the graph. A conventional dummy load is connected across the primary of the welder to insure stable operation of the synchronous ignitron weld timer.

Figure 3 is a photograph showing a laboratory welder being set up for an electrode test with the sequencing measuring circuits connected. In the background of Fig. 3 are two coolant flow meters, called Rotometers, connected to the upper and lower electrode holders cooling system, giving a continuous indication of the rate of coolant flow through the electrodes. The coolant

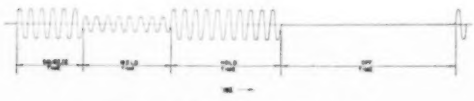

Fig. 2 Welder sequencing cycle

Fig. 3 Welder setup for measurement of sequencing

flow is adjusted to a predetermined value and equalized in each holder prior to commencing a test run. The Rotometers are also used to measure coolant flow rates in various Mallory electrode holders and aids in establishing holder design to permit maximum coolant flow rates.

Measurement of welding current and weld timing is frequently accomplished using an air core toroidal coil mounted around an electrode holder. The flow of welding current through the electrode holder produces an induced voltage in the toroid coil, the magnitude of which is directly proportional to the welding current. The induced voltage is not, however, in phase with the welding circuit but may be integrated by a simple resistance-capacitance circuit (Fig. 4) to reflect the wave shape of the welding current. Figure 4 shows a cathode-ray oscilloscope and associated calibrating circuit connected with an air core toroid pick-up coil.

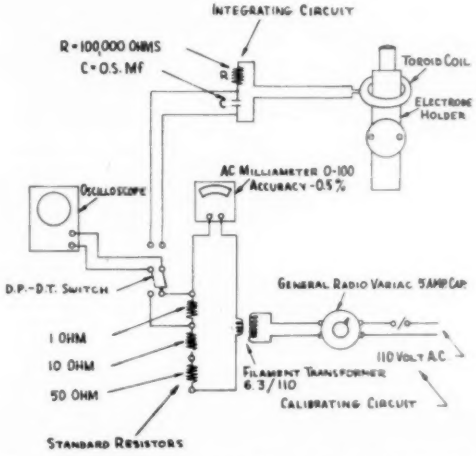

Fig. 4 Circuit diagram for welder current measurement

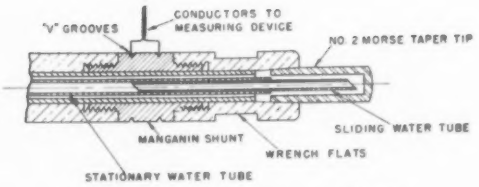

Fig. 5 Manganin shunt electrode holder

The welding current may be measured by connecting the oscilloscope to the integrating circuit of the toroid coil and adjusting the scope gain control until a deflection of convenient amplitude is obtained on the screen. Without changing the gain control, the measuring circuit is then applied to the scope, and the current adjusted until the deflection of the beam is the same as obtained from the toroid coil. The voltage impressed on the scope from the measuring circuit is then calculated by Ohm's law and represents the value of voltage output of the toroid integrating circuit. Having previously calibrated the toroid coil, the magnitude of the welding current may be readily calculated.

Initial calibration of the toroid coil may be accomplished using a manganin shunt type electrode holder (Fig. 5). This holder is a standard electrode holder except an insert of manganin, a metal of high specific resistivity and low-temperature coefficient of resistivity, is built into the holder body. The resistance of the manganin insert is determined on a low-resistance measuring bridge, and the welding current passing through the holder is calculated after measuring the voltage drop across the manganin insert. Thus with a toroid coil around the holder, the coil may be calibrated and a curve of the integrating circuit output voltage as a function of welding current may be plotted.

The toroid coil, while requiring initial calibration, is more flexible and convenient to use than the manganin shunt type holder. However, the toroid coil must be connected to a high-impedance circuit so as to draw a negligible current. The toroid coil may be used with such measuring or recording devices as the cathode-ray oscilloscope, Brush crystal type oscillograph or vacuum tube volt-meter. The current and timing measuring devices are occasionally used to check the operation of production welding machines suspected of faulty electrical or mechanical performance. By suitable adaptions of the circuits, the performance and synchronization of other welder components may be determined such as welder-limit switches, solenoid-operated valves, solenoid-operated relays, etc.

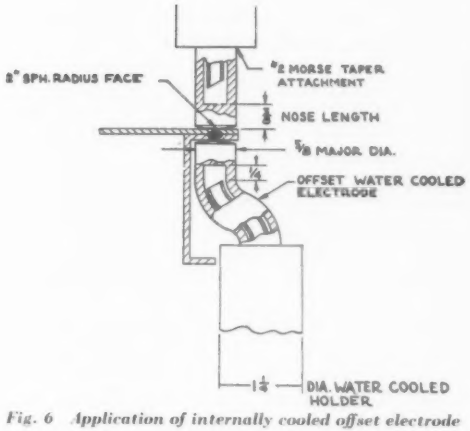

Fig. 6 Application of internally cooled offset electrode

Performance tests are carried out on all new or improved resistance-welding electrode designs, as for example Fig. 3 illustrates the setting up of test equipment for determining the performance of the new internally water cooled, bent type, offset spot-welding elec-

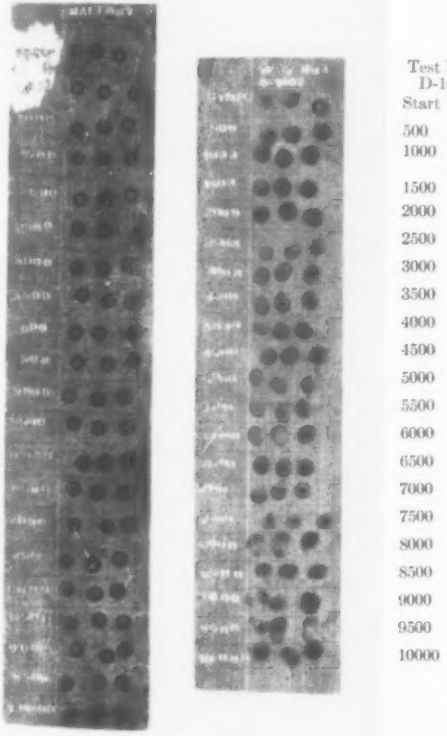

Fig. 7 "Weld log" sheet for comparison of spot-weld surface appearance

trodes. A production application of the internally cooled bent-type electrode, Fig. 6, is the spot welding of aluminum alloy sheets where the more efficiently internally cooled offset electrodes minimize "pick-up" of aluminum on the tip face. Here the electrode is sectioned showing the inner cooling tube projecting up into the tip coolant hole.

During test runs on electrodes, in addition to periodic measurement of dimensional changes of the electrode face, a "weld-log" sheet is maintained which provides a permanent record of the weld surface appearance and indentation. The weld-log sheet is also used for radiographic examination of the welds.

Figure 7 shows two weld-log sheets made during the testing of a special refractory metal spot-welding electrode identified as Elkonite D-1607. A set of Mallory 3 electrodes were run under the same conditions as "control" electrodes. The "log" sheets are the same material as was welded during the test run and, at 500 weld increments, three spot welds were made of the log sheet.

The surface appearance of the welds made by the Elkonite D-1607 electrodes had become decidedly irregular after about 2000 welds, indicating the electrode face was making poor and inconsistent contact. Radiographic analysis disclosed unsymmetrical welds after 3000 spot welds. This condition resulted from rapid deformation of the faces of the D-1607 electrodes and a comparison of the weld-log sheet reveals the marked superiority of the Mallory 3 control electrodes.

III. DIE AND FIXTURE DESIGN AND WELDER MODIFICATION

The services of the laboratory are frequently required in the design or improvement of resistance welding dies, or the modification of a welding machine to perform a specific operation.

A particular resistance welding application involved the welding of a tungsten contact to a high-carbon spring steel blank, the elements of which are shown in Fig. 8. The contact is located in a nest in the lower electrode and the steel blank is located on top of the contact by means of insulated locating pins. This contact assembly was a high-production item and the original lower electrode consisted of a Mallory 3 tapered shank tip into which was press fitted on Elkaloy "A"

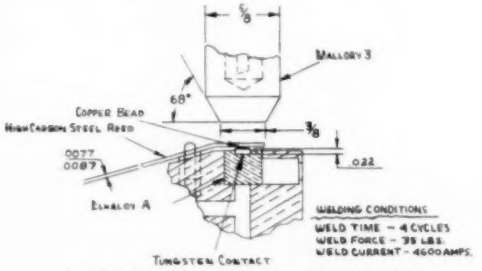

Fig. 8 Setup for welding contact assembly

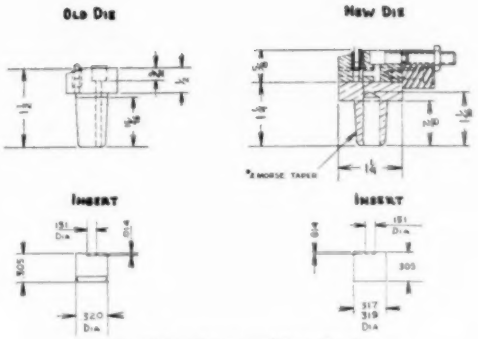

Fig. 9 Old and new welding die design

insert. The insert was made completely by machining. (See Fig. 9.) There were several disadvantages of the original fixture.

As inserts were continually press-fitted into and out of the electrode, the size of the hole became enlarged necessitating making the inserts in small quantities and machining the outside diameter to fit the hole. To obtain good electrical contact and avoid water leakage, the inserts were largely tailor-made to fit the various hole diameters of the electrode.

A further disadvantage was that, to remove the insert, it was necessary to remove the entire electrode from the welder, insert a rod into the hole to drive the old insert out and then press in a new insert. In addition, the seat of the insert nest could not be made consistently flat and even and irregularities in the nest seat resulted in frequent cracking of the tungsten contact disk during welding due to poor pressure distribution. To overcome the disadvantages, a composite electrode was designed into which the inserts could be slip fitted and securely clamped in position without danger of deforming the hole in the electrode. Small holes were drilled leading from the bottom of the insert to an exterior surface of the electrode. The insert was removed from the electrode by loosening the clamping screw and inserting the nozzle of a compressed air hose into the hole leading to the insert bottom, and with a blast of air, the insert was ejected. This method of clamping the insert permitted the inserts to be made in large quantities by cold heading on standard heading machines.

The manufacturing cost of the new inserts was about one cent each as compared to seventy-five cents for the old machined insert. In addition, the seat of the nest was made flat and smooth by the cold heading operation and closer dimensional tolerances maintained. The new electrode need not be removed from the welding machine except for infrequent cleaning.

Figure 10 is a photograph of the original and new electrode. The taper shank portion of the new electrode rarely requires removal from the holder and, hence, requires no maintenance.

A second problem on the same job arose involving the mechanical operation of the welding machine. The

Fig. 10 Photograph of old and new die

particular machines were automatic motor driven welders, and the up and down stroke of the movable welding head was governed by an operating cam. With a welder speed of 85 strokes per minute, required to meet production schedules, the total duration of the applied welding force or "pressure period" did not permit a sufficiently long "hold time" to be maintained. The operator had to weld contacts on each end of the steel blank. It was necessary to grasp the welded end in turning the blank around to weld the second contact but the short "hold time" left the blank too hot to handle.

The original cam motion curve is shown in Fig. 11 and the total pressure period was 11 cycles. The welder sequence was 2 cycles squeeze time, 4 cycles weld time and 5 cycles hold time.

A new cam was designed (Fig. 12) which increased the pressure period to 20 cycles, the sequence was then adjusted to 4 cycles squeeze, 4 cycles weld and 12 cycles hold. The longer "hold time" cooled the blank completely before the head retracted. However, after a period of time, considerable cracking of the tungsten contacts during welding was being encountered. This was the result of the impact force applied when the upper electrode touched the work.

A third cam was designed (Fig. 13) incorporating a "pause period" during which the velocity of the moving head was substantially reduced as the upper electrode touched the work. The impact force was minimized without reducing the speed of welding, and cracking of

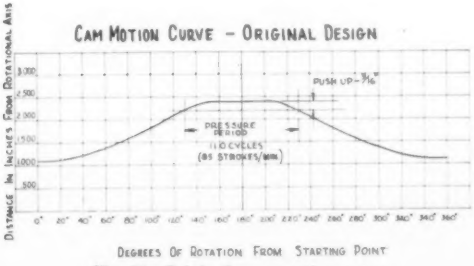

Fig. 11 Original cam motion curve

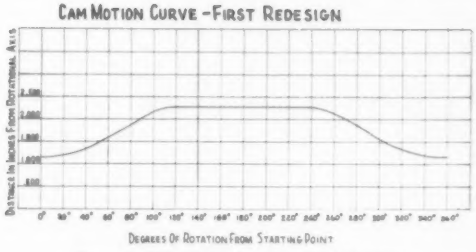

Fig. 12 First redesign of operating cam

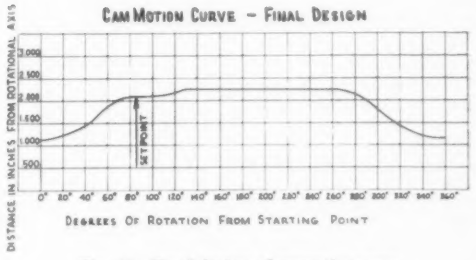
CAM MOTION CURVE - FINAL DESIGN
DISTANCE IN INCHES FROM ROTATIONAL AXIS
SET POINT
DEGREES OF ROTATION FROM STARTING POINT

Fig. 13 Final design of operating cam

the tungsten contacts was reduced to a negligible amount. A photograph, Fig. 14, shows the three operating cams.

IV. ELECTRICAL UPSETTING APPLICATIONS

The proper adaptation of known resistance-welding techniques to production applications is readily accomplished in the resistance-welding laboratory. One example is the electrical upsetting of a threaded stud into a steel plate. The application required suitable design of the parts, construction of welding fixture and determination of welding conditions. The sketch, Fig. 15, discloses the laboratory setup for the upsetting of the stud and consists of a lower combination fixture and die in which the stud is inserted and securely clamped. The clamping avoids damage to the threads of the stud and permits good electrical contact between the stud and die. The extension of the stud shank out of the clamping die is held to a practicable minimum thus avoiding overheating of the stud section under the plate.

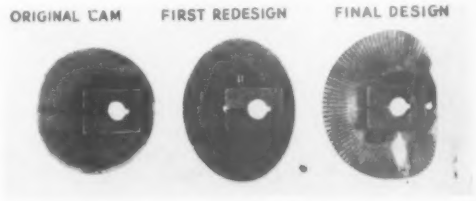

Fig. 14 Photograph of operating cams

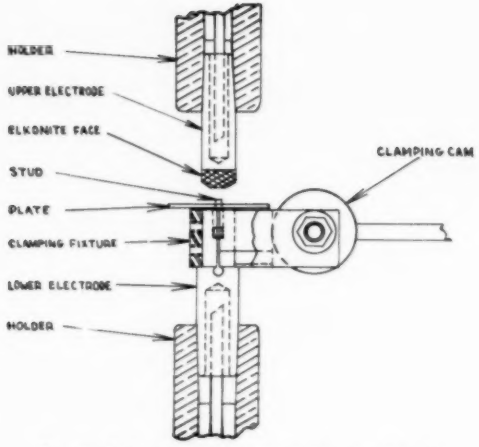

Fig. 15 Setup for electrical upsetting application

Prior to development of the electrical upsetting method, the stud was mechanically spun or staked into the hole, the hole being punched square, and when a nut was tightened on the screw of the stud during an assembly operation, the stud frequently turned in the hole causing frequent rejects and excessive cost. No such failures occurred using the electrically upset stud since the metal flowed completely into the square hole during upsetting.

The welding conditions found satisfactory for uniform upsets were as follows:

Heat time	8 cycles
Weld force	375 lb.
Current	2600 amp.

Fig. 16 Pilot run of electrical upsetting application

The lower electrode, shown in Fig. 15, is a standard Mallory 3 flat-faced electrode into which was drilled the hole for the stud and a thin milling cutter was used to make a slot so that the cam could clamp the split halves together on the stud. The upper electrode which does the upsetting was a 20W3 Elkonite faced tip. In designing composite fixtures and dies, standard electrodes are used wherever possible.

The laboratory frequently makes a pilot run of new welded products to work out the "bugs" in fixtures and procedures. Figure 16 is a photograph of a laboratory resistance welder setup for a pilot run on the assembly described. The use of a low inertia–low pressure electrode holder, in the upper arm of the welder, was necessary since the conventional pressure system of the welder possessed too great an inertia and force for the particular application.

V. SPOT WELDING HIGH-CARBON STEEL STRIP

An application of spot welding high-carbon steel (spring steel) consisted of joining the ends of a thin strip to form a continuous band. The strip, 0.007 in. thick by 6 in. wide, was joined by a series of spot welds, see Fig. 17, with the strip ends overlapped $^3/_8$ in. In service, the bands were run over a series of pulleys which necessitated certain joint requirements. Selected by laboratory tests was: the minimum overlap, proper weld pattern and spacing, optimum weld diameter and location of the band ends.

Conventional spot welding of the high-carbon steel produced an extremely brittle weld area which would not withstand the repeated stressing of the joint as the band joint was bent around the pulleys. A postheat current was applied to the spot welds in the welding machine which restored sufficient ductility to the welds to withstand the repeated stressing. Both upper and lower electrodes were Mallory 3 metal tips, $^1/_2$ in. diameter with a $^1/_8$-in. diameter welding face and a 30° rake angle approach. Prior to welding, the blue oxide was removed from the surfaces of the steel strips of the weld area.

A photograph, Fig. 18, illustrates the laboratory setup for making the welds. The band is located by pins in the lower fixture plate, the lower electrode pro-

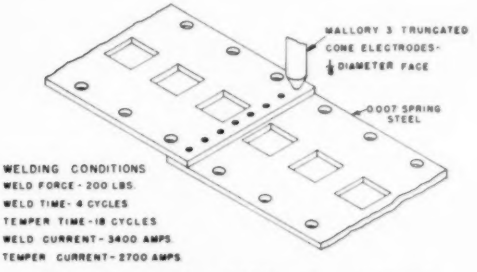
MALLORY 3 TRUNCATED CONE ELECTRODES-
1/8 DIAMETER FACE
.007 SPRING STEEL
WELDING CONDITIONS
WELD FORCE - 200 LBS.
WELD TIME - 4 CYCLES
TEMPER TIME - 18 CYCLES
WELD CURRENT - 3400 AMPS.
TEMPER CURRENT - 2700 AMPS.

Fig. 17 Spot welding of high-carbon steel bands

Fig. 18 Welder setup for spot welding high-carbon steel bands

jects up through an elongated slot in the lower plate and the entire plate slides in and out on a large bakelite guide plate. The bakelite guide plate had gage lines marked on the side to properly space the welds.

VI. TESTS ON RESISTANCE-WELDING ELECTRODE HOLDERS

Tests are made on all new or modified electrode holders to determine performance and operating characteristics. Mechanical strength, cooling and deflection are investigated and new water-sealing devices are subjected to life tests.

On ejector-type holders, performance tests are made to insure the strength and sturdiness of the ejector mechanisms. All straight holders are designed to pass a minimum of 2 gal. per minute of water with a 25 psi. water pressure with 10 ft. of connected standard hose.

A typical test on a straight ejector type holder, Fig. 19, is designed to investigate the wear characteristics of a new device which seals off the coolant chambers of the holder. A motor-driven cam applies repeated reciprocating motion cycles to the ejector plug. The test procedure is standardized and periodically full water pressure is applied to the holder to determine if the sealing device is still watertight.

Extensive laboratory investigations have been conducted on standard offset-type electrode holders, the mechanical form of which is that of a cantilever beam having one end fixed and loaded at the other. Dissatisfaction is sometimes encountered in the use of standard offset-type holders resulting from two basic causes.

1. An excessive load is applied to the holder which stresses some critical section beyond the proportional limit of the metal, resulting in permanent deformation or fracture.
2. The applied load is sufficiently high to cause objectionable deflection of the holder, resulting in spot welds of poor quality, consistency and appearance.

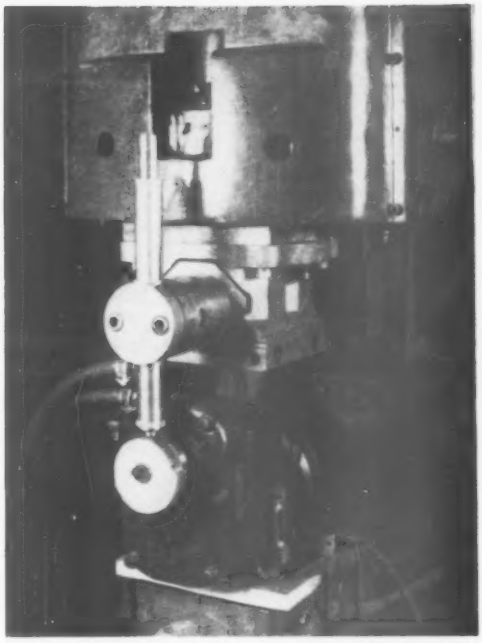

Fig. 19 Performance test on ejector holder sealing device

Such failures might be avoided if the user of the holder was provided with factual information regarding maximum permissible load which may be applied to the holder and the amount of deflection caused by various forces within the maximum safe loading of the holder.

Fig. 20 Measurement of deflection of offset-electrode holder

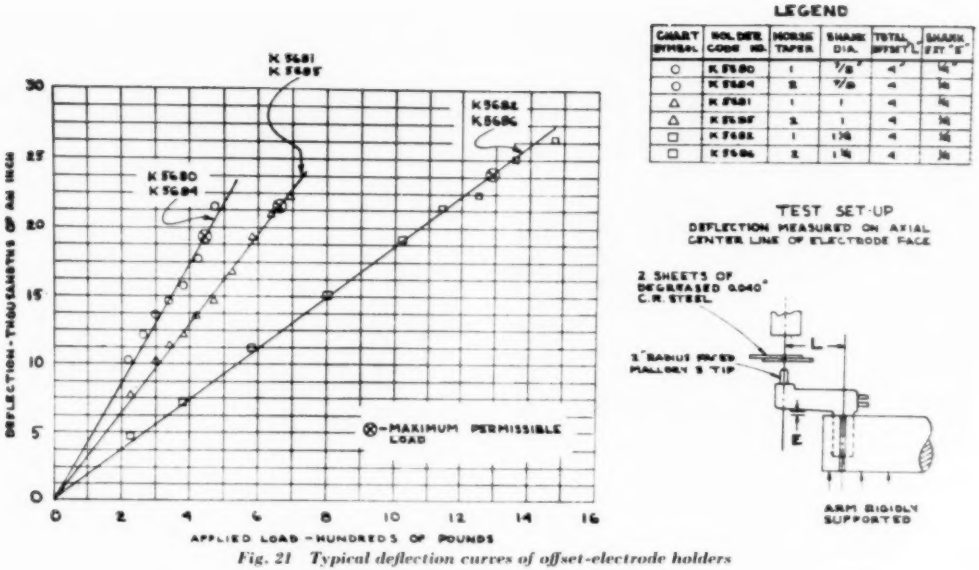

Fig. 21 Typical deflection curves of offset-electrode holders

This was the intent of a laboratory investigation, Fig. 20, involving the measurement of deflection as a function of applied loads on all standard offset and universal offset electrode holders.

The test setup, Fig. 20, reveals the use of a dial indicator arrangement for measuring deflection, the load being obtained from the welder-pressure system after first having been carefully calibrated. Two sheets of degreased steel were used between the electrodes to similate actual service conditions. The information derived from this investigation was compiled in the form of a family of curves, Fig. 21, and graphs were made available to the Sales Department in a complete report. Calculations were made of maximum permissible loads and were included in the data. In the course of these tests, several deficiencies were uncovered in the original holder designs, which led to structural improvements.

VII. RESISTANCE WELDING OF CONTACT ASSEMBLIES

There is continual need for the experimental resistance welding of contact assemblies to establish correct procedures, electrode materials and welding conditions. The wide dissimilarity of the metals comprising contact assemblies require much consideration in the selection of electrode materials and welding conditions to obtain a suitable heat balance. One such application is the welding of a small silver-tungsten carbide rectangular contact to a 0.062-in. thick copper blank. The electrode arrangement, Fig. 22, consists of a molybdenum faced upper electrode against the copper blank, while the contact rests on a Mallory 3 metal lower die face.

The purpose of the welding experiments was to determine the strength of the welded joint as affected by different welding conditions. A thin masking plate of stainless steel locates the contact on the lower die and the blank is placed over the contact being positioned by a bakelite guide. A stream of water is played on the

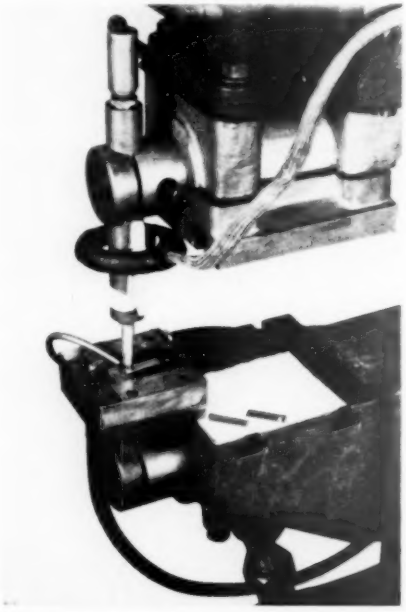

Fig. 22 Welder setup for welding of contact assemblies

assembly during welding to prevent overheating of the contact and to minimize oxidation and annealing of the copper blank.

In Fig. 22, the assembly is in position for welding, the electrode is on the work and the entire weld area is being flood cooled. The air core toroid coil is used to measure the welding current and weld timing.

VIII. MAKING "INVISIBLE" SPOT WELDS

The spot welding of a 0.020-in. nickel-plated mild steel spring clip to a 0.052-in. cadmium-plated steel blank requiring an "invisible" weld on the cadmium plated blank was easily accomplished. With conventional spot welding procedures, the customer could not avoid some disturbance of the cadmium plating during welding, resulting in a plainly visible marking on the blank. When using a flat or large radius faced Elkaloy "A" electrode against the cadmium plated blank (setup shown in Fig. 23), laboratory experiments failed to completely eliminate some disturbance of the plating.

To reduce the current density at the back of the cadmium-plated blank, the edges of the blank were clamped to the lower electrode, thereby permitting the welding current to be distributed over a larger area at the blank to electrode contact. This experimental

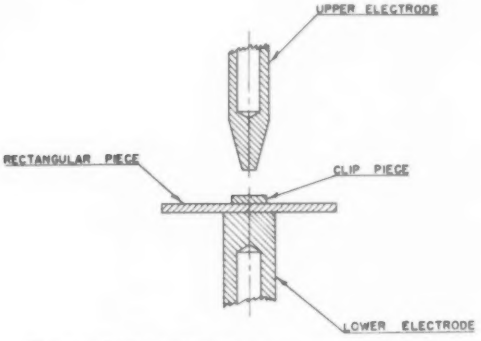

Fig. 23 Original electrode arrangement for making "invisible" spot weld

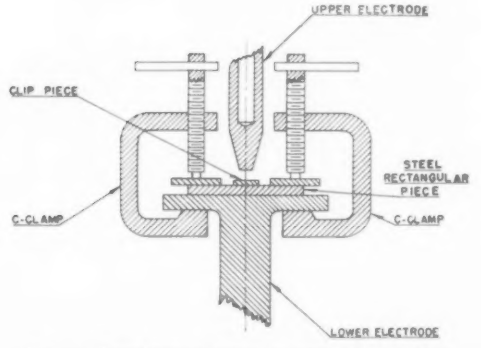

Fig. 24 Experimental setup for minimizing surface disturbance

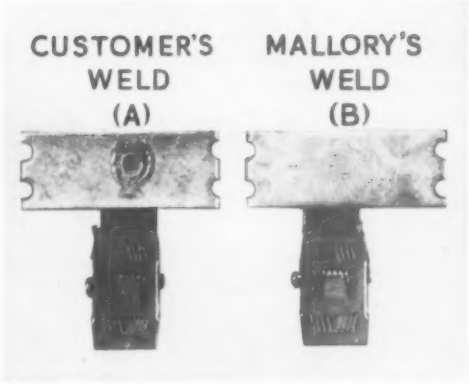

Fig. 25 Device for measurement of contact resistance

setup, shown in Fig. 24, effectively reduced the heat effects at the contact surface and produced an "invisible" weld. A mechanically operated device for clamping the blank to the lower electrode was developed for production practice. Expedients, such as these, have to be resorted to frequently where a large quantity of parts are made up prior to determining if they are suitable for welding. In this particular case, perhaps the use of a nickel-plated blank would have avoided the necessity of using the clamping device.

The photograph, Fig. 25, is an indication of the surface appearance of the blanks as spot welded by the two procedures.

Surface conditions of the materials to be spot welded frequently require investigation since weldability is often affected by oxide or other films on the metals. To

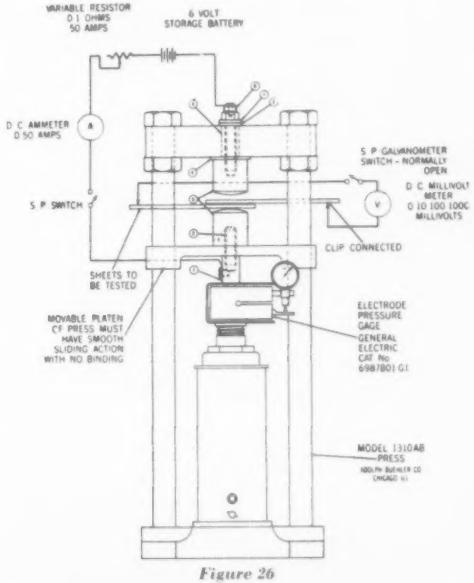
VARIABLE RESISTOR 0.1 OHMS 50 AMPS
6 VOLT STORAGE BATTERY
D.C. AMMETER 0-50 AMPS
S.P. GALVANOMETER SWITCH - NORMALLY OPEN
D.C. MILLIVOLT METER 0-10-100-1000 MILLIVOLTS
S.P. SWITCH
CLIP CONNECTED
SHEETS TO BE TESTED
MOVABLE PLATEN OF PRESS MUST HAVE SMOOTH SLIDING ACTION WITH NO BINDING
ELECTRODE PRESSURE GAGE GENERAL ELECTRIC CAT. NO. 698T801 G1
MODEL 1310AB PRESS

Figure 26

determine the nature of the surface films and the efficiency of the metal surface preparation or cleaning methods, a relatively simple contact measuring device, shown in Fig. 26, is used.

IX. SUMMARY

The welding equipment in a resistance-welding laboratory must be capable of being adapted to an extremely wide variety of applications and the use of flexible and dependable synchronous timing and sequencing controls are mandatory. The size of assemblies to be welded ranges from tiny phonograph needle tips to heavy-gage structural steel plates.

In the Metallurgical Research Laboratory, complete facilities are available for analysis of welding problems, such as radiographic, metallographic, spectrographic and chemical analysis.

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Metallizing in Relation to Marine Engineering

Equipment used to spray metal, characteristics of the coating produced, methods by which bonding to the base material may be achieved and techniques for finishing sprayed metal coatings. Applications of the process to marine engineering are conveniently divided into: (a) the reclamation of worn parts, and (b) protective coatings to resist corrosion

by J. Barrington Stiles, M.I.Mech.E.

THE PROCESS

METALLIZING can be defined as a process whereby heated metal in a finely divided state is projected onto a receiving surface by means of an air blast. Figure 1 shows metal spraying being carried out for the protection of steelwork, exemplifying its original purpose although the particular application—zinc spraying a steel hull—is a comparatively recent innovation in this country. In order to obtain a balanced conception of the usefulness of the process, Fig. 2 is included to illustrate the reclamation of worn machinery parts—in this case spraying stainless steel on an auxiliary turbo-pump shaft. Both classes of work are of interest to marine engineers, but a brief study of the process itself is essential for the intelligent application of either of them.

Fig. 1 Sandblasting and zinc spraying a steel hull

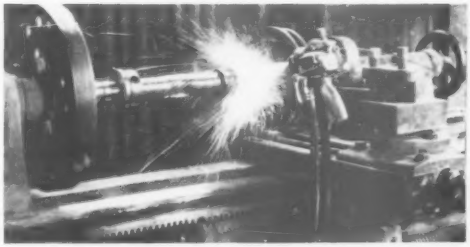

Fig. 2 Auxiliary turbo-pump shaft being metallized with stainless steel

During its development, metallizing has passed through stages in which first molten metal, then powdered metal and finally wire has been the state in which the material has been fed into the hand tool, known as the metal-spraying gun. The convenience of storage and handling of metal in wire form need scarcely be stressed, although emphasis should be placed on the fact that in the case of wire, the necessity to melt it in order to atomize it implies that every particle must have been adequately heated, whereas with molten metal or powder neither may be deposited with the same guarantee of heat control. Thus, it is not surprising to find that the wire-type of metallizing gun is the one in most general use today. The range of wire metal spraying is limited only by what materials may be obtained in wire form, so that all the common metals and alloys may be sprayed, with the exception of pure chromium.

Figure 3 shows the general arrangement of a typical modern metallizing installation with the gun fixed to the toolpost of a lathe. A governor-controlled, high-speed air-turbine through double worm-reduction gearing to a pair of feed-rollers pulls the wire into the gun and pushes it through the central orifice of a close-fitting nozzle. Figure 4 is a diagrammatic representation of the melting and deposition of the wire. A mixture of gas and oxygen is led to the nozzle tip by means of small passages, usually six in number, so as to play small jets

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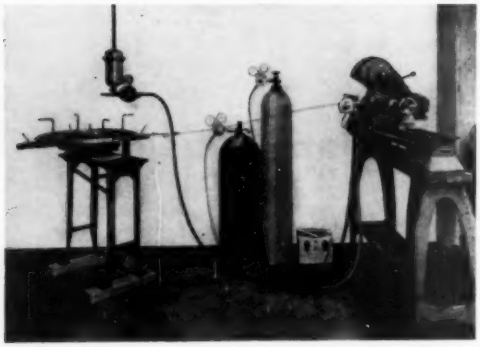


Fig. 3 Arrangement of metallizing gun in lathe showing controls for air, gas, oxygen and wire

of flame on to the wire. Thereafter, an air-stream breaks up the melting wire into small particles, at the same time directing the jet of metal on to the work. The mean temperature of the stream, consisting as it does of a small volume of hot metal and a large volume of cool air, is quite low—so low indeed that it may be directed on to the hand without any considerable discomfort.

An individual particle, once separated from the wire, assumes a roughly spherical shape and is subject to cooling and oxidizing conditions during its flight, which may occupy about one-thousandth of a second. On impact, and according to varying circumstances, the kinetic energy of the particle must largely change to heat, and, thereafter, in most cases it will be in intimate contact with a much larger and cooler body, so that rapid "quenching" results. Coincident with impact, the spherical shape of the somewhat oxidized and externally cooled globule will change to a spheroid, or may even become saucer-shaped. On flattening, the major perimeter will be the part most highly stressed and either cracks or torn, distorted edges will result. Maximum oxidization occurs during the period immediately following impact and continues until covering by subsequent particles has eliminated contact with the air.

From this simple study quite a lot of useful information can be derived as to the nature of sprayed metal. Perhaps the most interesting item is the manner in which

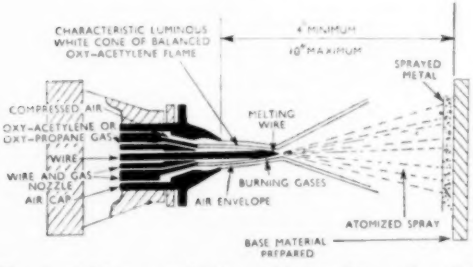


Fig. 4 Melting, atomization and deposition of metal showing section through combustion head of spray gun

the particles are joined together. Mechanical interlocking of the torn edges of particles accounts for much of the tenacity with which they hold together, but this is greatly increased by their tendency to flow on impact so as to key into one another. There is also undoubtedly some form of oxide cementation between particles, and this is probably the major factor in providing tensile strength normal to the surface being sprayed, whereas in a plane parallel to the surface mechanical interlocking provides tensile strength which may be even ten times as great as that normal to the surface. A certain amount of rather haphazard welding does occur between particles here and there in a coating, but is generally of little importance in considering the strength.

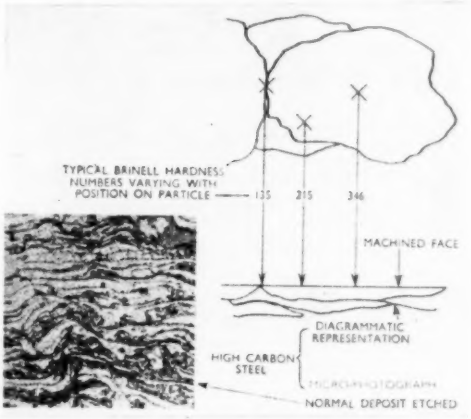


Fig. 5 Variations in apparent hardness due to structure of sprayed metal

Figure 5 represents diagrammatically several typical particles of sprayed steel, and indicates how misleading an ordinary hardness test can be as shown by readings taken in the center of a particle, nearer the edge, and again at the junction of two particles. The normal difficulties of making due allowance for the coating thickness and the nature of the base material are insignificant compared with the errors arising from the positioning of the test on the particle.

If machining properties are to be considered in relation to hardness, then it is obvious that the properties of the oxides separating the particles must not be overlooked and it must be decided whether the cut will be parallel to the laminations or across them; the "apparent" oxide content being much less in the former than in the latter case, since, although each particle covers a relatively large area, it has very little thickness. Figure 5 includes a microphotograph of sprayed steel which is obviously porous, though not so much by reason of minute voids as by the oxide layers.

Table 1 tabulates hardness for a range of common metals in the sprayed condition, but is mainly of academic interest, because other factors, such as the porosity and oxide content, have a greater influence over

Table 1—Hardness Values and Decreased Specific Gravities After Spraying

Sprayed metal	Hardness, equivalent Brinell No.	Ratio of coating specific gravity to that of wire used, per cent
High carbon chromium steel	296	88·7
80 per cent carbon steel	346	82·5
10 per cent carbon steel	183	86·7
Iron	147	88·4
18/8 Stainless steel	147	88·9
Naval brass	76	89·2

wear-resistance and machining properties. Shepard* has obtained values for the relative specific gravities of various metals and alloys when sprayed as compared with the wires used, expressed as a percentage, and these have been included in Table 1.

The coating will absorb a great deal of liquid under pressure, and even a substantial amount by capillary attraction. Sprayed metal, when used to form a journal-bearing surface, provides a natural oil reservoir, thus eliminating dry-starting conditions with a consequent lessening of wear. It is interesting to note that in the case of crankshafts, records indicate that the performance of sprayed metal compares favorably with the hardest shafts, and that for this purpose there is very little to choose between metallized coatings of soft low-carbon steel or the hardest of high-carbon steels. One cannot avoid concluding that it is the porous nature of sprayed metal that accounts for its excellent properties as a journal-bearing surface. The typical stress-strain curve* shown in Fig. 6 indicates some similarity to a cast material.

Shrinkage of sprayed metal during cooling provides the chief source of stress in a metallized coating, and it varies rather surprisingly as indicated in Table 2. It is obvious that contraction serves to tighten the bond when a periphery is being metallized while the converse is true of internal work on bores, but in general shrinkage should be held to the minimum, as it prestresses and weakens a coating, and may in some cases result in cracking. The permissible amount of shrinkage will depend on several factors, foremost among them being the amount of metal being deposited and the standard of preparation achieved on the receiving surface.

Surface preparation is by far the most important part of metallizing technique since upon its adequacy depends the strength of the bond between the coating and the parent metal. There are numerous methods by which bonding can be achieved, but most of them involve roughening the surface in such a manner that the sprayed metal is mechanically keyed in position by means of suitably shaped depressions in the base material. To produce a strong mechanical bond such surfaces must be rough and free from oil, moisture, etc. As will be seen in Fig. 7 the degree of roughness must be sufficient to allow average-sized particles of sprayed metal to enter the depressions without "bridging" them, and the shapes must include a high percentage of undercut depressions in which the deposit can anchor.

A second function of mechanical preparation must not be overlooked. It consists of breaking up the surface so as to expose not only a much increased area of contact, but also to tilt the particles of sprayed metal at widely different angles. It has already been noted that the laminar structure yields much greater strength

* A. P. Shepard, Metco Laboratories, Long Island City, N. Y.

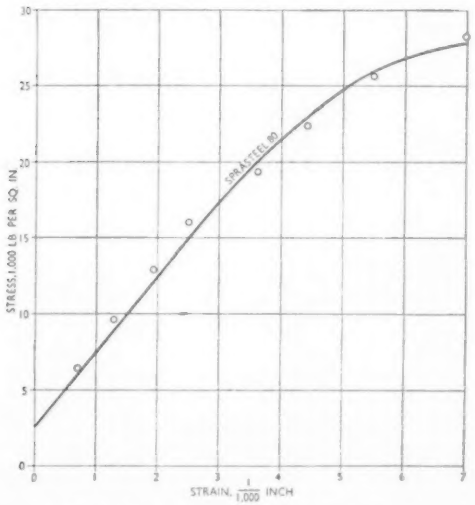


Fig. 6 Typical stress-strain curve for steel

Table 2—Internal Stresses in Sprayed Metal Coatings Arranged in Order of Their Relative Ability to Resist Them

Metal	Shrinkage, per cent	Elongation, per cent at ultimate strength	Ultimate tensile strength, lb. per sq. in.	Remarks
High carbon high chromium stainless steel, No. 2	0·18	0·50	40,000	Internal stresses low; coating strong—the most reliable metals for building-up heavy duty parts
80 per cent carbon steel	0·14	0·42	27,500	
10 per cent carbon steel	0·80	0·30	30,000	High stresses—care must be taken to ensure a good bond
Iron	0·90	0·25	28,000	
18/8 Stainless steel, No. 1	1·20	0·27	30,000	Strong bond essential and slight pre-heating in cold weather to prevent risk of cracking
Naval brass	1·00	0·51	13,000	

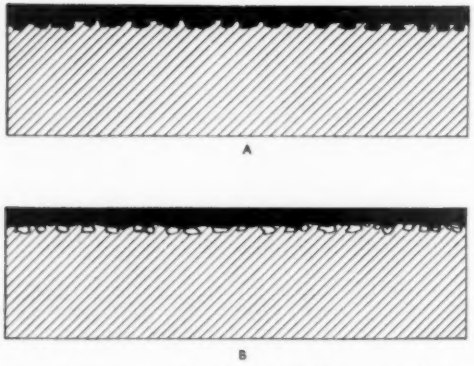


Fig. 7 (A) Character of bond attributable to good blasting preparation. (B) Bridging caused by too fine blasting

parallel to the laminations than at right angles to them, and it follows that an irregular surface will distribute this strength more uniformly throughout the coating. While not significant in the case of protective coatings, this factor assumes considerable importance on machine element work and often dictates which method of preparation shall be employed on a particular item. The roughness should, therefore, be of such an order as to "anchor" the coating against contraction stresses, but patterned so as not to produce a change of plane along any given line. A splined shaft is an example of exaggerated roughness without anchorage in some directions and definite weakness along axial lines of maximum stress, where change of shape alters the plane of lamination.

Since various classes of work demand different methods of preparation it is well to understand the several techniques employed and compare their advantages and limitations.

Blasting with Sand or Angular Steel Grit

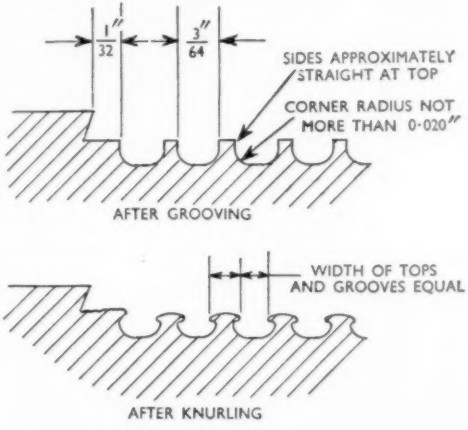
Grade 24 abrasive used at about 70 psi. pressure produces on mild steel and other not too hard surfaces irregular depressions which will key sprayed metal. It is by far the cheapest method of surface preparation, but the bond obtained does not permit heavy deposits, being inadequate to resist severe contraction stresses. Figure 7 (*A*) represents an enlarged section through a well-blasted surface. The human element enters into sandblasting to such a degree that it cannot be considered reliable, the more so because visual inspection does not easily reveal slightly defective workmanship. It is usual, when employing the blasting process, to rely on rigid control of air pressure and quality of abrasive used and limit inspection to insistence on complete and uniform treatment of all surfaces. Hard cast-iron and heat-treated steels are sometimes blasted with alumina and other extremely hard abrasives, but a similar limitation as to coating thickness still applies.

Rough Turning

This generally produces a bond superior to blasting, although, relying on the small barbs torn up on the surface, it is dependent on the strength of the parent metal, so that in the case of cast iron, brass and similar materials, it is not very useful. A sharp-pointed V-tool ground to about 40° and having little rake or clearance is normally employed to cut from 16 to 24 threads per inch according to the size of workpiece and thickness of coating. Some little skill is required to produce consistent results. Engineers may well look askance at a process involving tearing jagged cuts by way of preparation, but the incidence of failure by fatigue of such work appears to be extremely low, in fact, no instance of such failure has come to the author's notice during the fourteen years he has known the technique to be employed. This may, however, be due largely to the wide margin of safety employed by engine designers, and methods other than rough turning are used by most responsible engineers engaged in the metallizing industry.

The Shaft Preparation Tool Method

This involves roughening the surface with a special type of knurling tool, using a laminated cutter in which


1/32"
3/64"
SIDES APPROXIMATELY STRAIGHT AT TOP
CORNER RADIUS NOT MORE THAN 0·020"
AFTER GROOVING
WIDTH OF TOPS AND GROOVES EQUAL
AFTER KNURLING
PITCH OF GROOVES
14 TO THE INCH FOR CAST IRON
16 TO THE INCH FOR ALL OTHER METALS

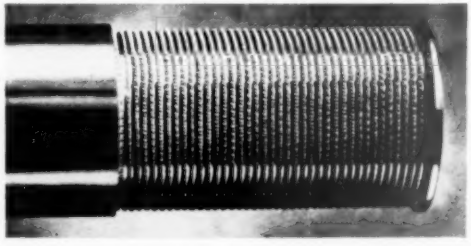


Fig. 8 Preparation of shafting by grooving and knurling

five thin steel blades, each with teeth set at different angles, are rigidly held together. When passed over the surface of a piece revolving in a lathe, a satisfactory kind of roughening is achieved, which has the advantage that uniform results can be repeatedly obtained. Used alone it is only satisfactory to receive coatings for press fits and other similar work in which the bond is not heavily stressed in tension.

The "Metco" Method of Shaft Preparation

This method, which was invented in the U.S.A. about ten years ago, remains the best method of machine preparation so far devised.

Figure 8 shows diagrammatically how a groove or thread is cut with a round-nosed tool and thereafter the ridges are spread over by using the shaft preparation tool. Although this method can only be employed on machinable materials, it does provide a means of producing uniform and reliable bonds over a wide range of machine element work. The technique is simple, and although two machine operations are involved (compared with one in the case of rough threading), it can be effectively performed by anyone who can use a lathe, whereas, except on mild steel, rough threading to the requisite standard can prove much more difficult than one might imagine.

Fuse Bonding

Figure 9 is a patented* method of mechanical bonding in which instead of relying only on deformation of the parent metal, as in all previous methods, there is fused to the surface a layer of rough and cratered material on to which the coating metal is subsequently sprayed. Since low-voltage, high-amperage current is required to heat a bunch of electrodes, a transformer, somewhat similar to that used for resistance welding, is employed. The chief advantages are that a good bond can be produced on even the hardest steel parts, and items which cannot be machined by reason of their peculiar shape or excessive size may be prepared for metallizing.

* British Patents Nos. 575128, 575129 and 575130.

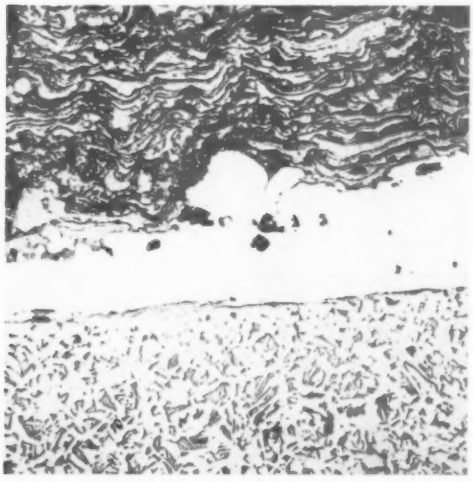


Fig. 9 Fusebond layer between sprayed steel and low-carbon steel base

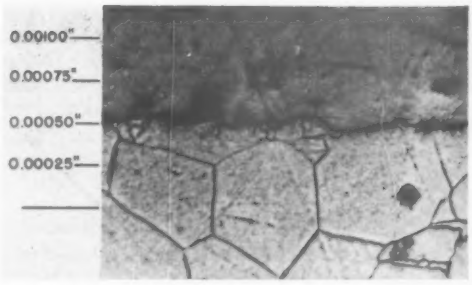


Fig. 10 Interface between layer of Sprabond and low-carbon steel base magnified to 1250 diameters

Sprabonding

This is the subject of patents and patent applications belonging to the Metallizing Engineering Co., Inc., of New York, and has only recently been used here. It appears to be an exceptionally good method of bonding coatings to almost all metals, with the exception of copper and cuprous alloys. It consists of spraying a thin layer (about .0015 to .002 in. in thickness) of a special material on to the base metal, and thereafter applying whatever metal may be required, according to normal metallizing practice. The adhesion between the "Sprabond" and the parent metal is molecular and of the same character as that obtaining between, say, brazing material and steel, or between some metals and the oxides which so tenaciously adhere to them. Figure 10 shows a photomicrograph magnified to 1250 diameters, i.e., it is enlarged 1,500,000 times, so as to show the interface between a steel base and the sprayed layer of Sprabond. It is remarkable in that it indicates molecular adhesion and intimacy of contact equal to that between the crystals of solid steel. According to Ingham† alloying to an extent of 0.00003 in. thickness sometimes occurs between the Sprabond and the base, but no real penetration sufficient to disturb the physical properties of a steel base has been detected. The author's investigations have so far only confirmed that in addition to the adhesion between the Sprabond and base being more than adequate for any known application of the metallizing process, the bond between this special preparatory layer and the superimposed coating is of such a high order that when tested to destruction in tension or sheer, the failure has taken place in the metallizing and not at the bond.

It is, however, necessary to exercise scrupulous cleanliness on surfaces to be Sprabonded, the metal always to be exposed either by grinding, turning or cleaning

† Chief Engineer, Metallizing Engineering Co., Inc., New York.

with emery cloth. Degreasing is not satisfactory, nor is it possible to leave a cleaned part exposed to atmospheric corrosion before Sprabonding. Such care is, however, well repaid by the knowledge that a bond stronger than the sprayed metal itself has been obtained without risk of damage to the base metal.

Spray Welding

This forms a link between metallizing and welding. The material, known as "Metco Sprayweld H" is an extruded plastic in which are embedded certain metals which could not otherwise be made into a wire. Its applications to marine engineering are few but it is mentioned here because it has been successfully employed for the reclamation of Diesel engine gudgeon pins. The material is sprayed on to a surface which has been prepared either by blasting or machining, and is then heated either by oxyacetylene flame, high-frequency current or other means, so as to raise the surface temperature to between 1000 and 1100° C. in order that the deposit may flow and fuse to the base. The resultant coating is extremely hard, being in the region of 550 to 600 Brinell, which is considerably harder than any coating in the as-sprayed condition. Spray-weld deposits, however, do not have the property of oil absorption so that they are generally employed for such purposes as tipping agricultural machinery parts and coating earth-moving machinery blades. Its hardness, absence of porosity and excellent corrosion-resistant properties make spray welding very suitable for certain purposes which demand resistance to both wear and corrosion.

Bonding by Heat Treatment after Spraying

Use is made of the well-known property of aluminum by which it readily alloys with iron and steel at about 800° C. to protect ferrous metals subject to heat oxidation, by spraying pure aluminum on to a previously blasted surface and thereafter heat treating to produce the heat-resisting iron-aluminum alloy over the surface. Furnace parts are regularly so treated, and the coating becomes integral with the base material. There are numerous other examples of bonds achieved by heat treatment, but they are not important to an understanding of the more generally employed mechanical bonding methods which cover the bulk of metallizing work.

Hand Preparation

For metallizing this is generally to be avoided, although there are instances in which it can be very useful. One such occasion was during the late war when a destroyer (H.M.S. *Verity*) was found, on trials, to have distorted the port main turbine casing either side of the carbon packing gland, to a depth of about 0.008 in. on each flange. The vessel was required for immediate service, and the author, armed only with a metal spraying gun and some mild steel wire set out to get her to sea with the minimum delay. It was an all-night job to jack up the top-half casing, prepare the low areas on the flanges of both top and bottom halves, and metallize them—the preparation being carried out by making undercut chisel marks in three different directions at about 60° to each other. Admittedly, the deposited mild steel had only to perform "jointing" or "packing" duties, after filing and scraping by the dockyard staff, but it illustrates that hand preparation can be useful. On another wartime occasion severe pitting as much as $^5/_8$ in. deep in places was found aft of the stern glands and forward of the A-bracket bearings on each of H.M.S. *Stevenstone*'s propeller shafts. Time did not permit withdrawal of the shafts, and the author had to choose between gritblasting and hand preparation. The latter was selected (except that pneumatic chisels were employed) because the mass of metal required in some areas made it extremely doubtful whether blasting would prove satisfactory. This work was carried out as a temporary emergency repair, but long afterwards the Admiralty confirmed that it was still behaving satisfactorily. Some may wonder how machine finishing of the sprayed metal was carried out on these propeller shafts *in situ* in dry dock. The author claims no part in devising the method, which was suggested by the shipyard foreman, whereby these shafts were ground very true to a good finish by the simple expedient of cutting a wood block concave to the radius of the shaft and mounting a pneumatic grinder on it with a piece of rubber insertion to allow for pulling up to apply a cut. Figure 11, showing the arrangement used, is included not so much as illustrating a method of finishing sprayed metal, but as a tribute to that ingenuity which is found among marine engineers and shipyard staffs.

Preheating

This is not often resorted to in connection with preparing parts for metallizing, although a mild preheat is sometimes employed when metallizing internal surfaces such as bores and housings to counteract the effect of coating shrinkage. It must not in any case be carried

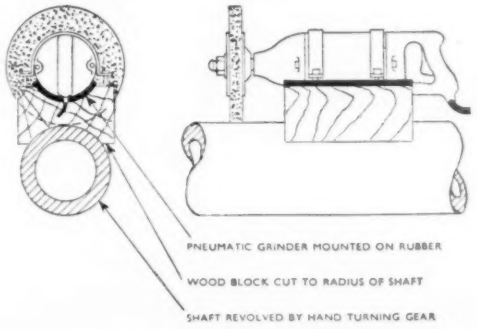


Fig. 11 Improvised grinding arrangements for propeller shaft metallized in situ on H.M.S. Stevenstone

Table 3—Effects of Preparation on Mechanical Properties (13% Chromium Steel on 3½% Nickel Steel Base)*

Type of preparation	Estimated endurance limit, 2×10^7 cycles	Stress concentration factor	Axial shear, lb. per sq. in., 2-inch cylindrical band 0·2 inch wide	Rotary shear, lb. per sq. in., 1-inch diameter × 2 × $\frac{1}{16}$ inch × 0·2 helix
Shot blasted with angular steel grit	54,000†	0·76†	1,200	3,150
Rough threaded	30,000	1·37	7,990	14,700
Grooved and knurled (complete "Metco" method)	27,000	1·52	6,000	25,400
Fuse bonded	35,000	1·17	9,000	24,100
Plain polished specimen	41,000	1·00	This specimen not sprayed	

* According to U. S. Bureau of Ships.

† Blasting with sand or steel grit stretches the surface and so prestresses it in a negative sense to those stresses which tend to cause fatigue in service.

to such an extent as to oxidize the prepared surface, and can only be used in conjunction with one of the mechanical methods of preparation already described. However, in extremely cold weather, with the workpiece at or below freezing point, it is considered advisable to "take the chill off the job" before preparing, since the surface if very cold rapidly collects moisture, and the mild preheating eliminates unnecessary stressing of the coating and so reduces the risk of low-temperature cracking. Average room temperature of about 60° F. is quite sufficient to obviate this, and the necessity to take any such action will vary with the particular metal being sprayed. As an example, high-carbon steel, which has comparatively high tensile strength, but low "shrinkage value" will not require such precaution in this respect as brass, of which the reverse is true.

Table 3 shows the effects of various types of preparation on the endurance and resistance to both axial and rotary shear stress.

FINISHING SPRAYED METAL

Table 4 indicates recommended feeds, speeds, etc., for finishing metallizing work by turning and grinding. Because of its peculiar structure, sprayed metal presents certain finishing problems to an uninstructed operator who has hitherto worked only on "solid" metals.

Turning

When a shaft has been metallized on to a machine-prepared surface, it may be found that at each extremity the coating is somewhat harder—in fact, a pronounced hard ring often occurs (Fig. 12). This is due to the flattened particles of sprayed metal being mounted more or less "on edge" in these areas, since they tend to follow the contour of the shoulder at each end of the prepared section. Such shoulders also collect particles of dust, carbon, etc. It can be minimized by spraying into the corners before proceeding with the main body of the coating. When it does occur, however, it is better to finish-machine the affected areas with a plunge cut rather than axial feed, using a blunt-nosed tool. With most sprayed metals there is a tendency for unskilled operators to tear out particles, resulting in a rough and pitted surface. Bad tearing may

Table 4—Feeds and Speeds for Finishing Sprayed Metal

Metal	Turning with carbide tipped tool				Dry grinding				Wet grinding		
	Surface speed, ft. per min.		Feed, inch per revolution		Tool post grinder, 5/6,000 surface ft. per min.				Wheels		All metals
	Roughing	Finishing	Roughing	Finishing	Metco wheel	Work speed, surface ft. per min.	Roughing feed per revolution, inch	Finish feed per revolution, inch	Carborundum 6,100 surface ft. per min.	Norton 6,500 surface ft. per min.	
High carbon steel	35	35	0·004	0·003	44	30	$\frac{1}{32}$	$\frac{1}{64}$	C36-K4-VE	37C46-K5V	Work speed, 80/90 surface ft. per min.
Low carbon steel	90	90	0·006	0·003	42	30	$\frac{1}{32}$	$\frac{1}{64}$	C36-K4-VE	37C46-K5V	Traverse, 3 ft. per min. (roughing)
Brass, bronze, copper	275	275	0·006	0·002	44	30	$\frac{1}{32}$	$\frac{1}{64}$	C36-K4-VE	37C46-K5V	Traverse, 1 ft. per min. (finishing)
18/8 stainless steel	110	150	0·006	0·003	43	30	$\frac{1}{32}$	$\frac{1}{64}$	A465-J5/6-V30	37C46-K5V	Infeed, none (finishing)
High carbon chromium steel	35	35	0·004	0·003	46	110	0·006	0·015	C36-K4-VE	37C46-K5V	Infeed, 0·001 inch (roughing)
Monel metal	225	275	0·004	0·002	46	30	0·006	0·015	GC-60-J8-VW	37C80-H7V	Coolant 45 to 1
Nickel	225	275	0·004	0·002	44	30	0·006	0·015	GC-60-J8-VW	37C80-H7V	

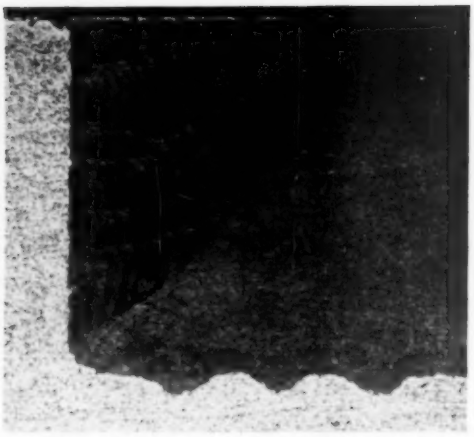


Fig. 12 Example of hard ring found at shoulder

even disturb particles which at the time are beneath the surface and so prevent a good finish being obtained at a smaller diameter. It is generally advisable to set the tool a little above the center so that front clearance is practically eliminated and the pressure of the tool immediately below the cutting edge will tend to hold each particle in position so that it will cut rather than tear out. Tungsten-carbide tipped tools should be used for all sprayed metals if possible because they require less rake and clearance than steel tools, and for the hardest materials, a grade which would normally be used for chilled cast iron should be employed.

Dry Grinding

This generally implies the use of a tool-post grinder, and the recommendations in the table should be closely followed, otherwise glazing the wheel and burning the coating will result. It is important to select the appropriate type of wheel for the particular coating, since selection based on experience of "solid" metals will yield indifferent results in most instances. All metals, when sprayed, lose some of their heat-conducting property by reason of the oxide surrounding each particle, so that they more readily overheat locally, especially when dry grinding is employed. For ferrous metals the Norton 37C46-15V wheel or an equivalent gives very good results.

Wet Grinding

Wet grinding provides the best possible machine-finish on sprayed metals. Wheels generally are coarser and of lower bond-strength than for normal metals, and if a general-purpose wheel is required, then either of the following vitrified wheels should be satisfactory: Carborundum C36-K4-VE or Norton Chrystolon 37C-46-K5V.

Lapping

Lapping should never be employed on metallized bearing surfaces, since the abrasive can become lodged in the pores of the metal with serious consequences.

Keyways

It is better practice to form a keyway during spraying by the insertion of a dummy key rather than to attempt to cut one in an otherwise unbroken periphery of sprayed metal. The latter procedure would release the contraction stresses in the coating and possibly damage the bond. Carbon is very suitable for making up into dummy keys, or for plugging oil holes, etc., while spraying, and presents little difficulty during machine finishing. When fitting a key the coating should be backed away so that the load is carried on the solid metal only.

Machining Allowance

Allowance is necessary to dispose of the top oxide layer, the natural matt surface of the sprayed coating, and any unevenness resulting from the rough contour of the preparation. As the coating thickness increases, the tendency for initial roughness to follow through decreases, so that the machining allowance becomes less. Generally 0.020 in. measured radially is sufficient when turning and about half that amount for grinding, but it is quite easy to assess what will be required from the character of the work.

Time Lag Between Spraying and Machining

When working to very accurate limits it is not only necessary to allow the sprayed coating to cool to room temperature, but also to allow it to settle down. Although contraction is a function of temperature the final adjustments in the material do not keep pace with the rate of temperature drop. While this does not affect the normal run of metallizing work, it has been found from time to time that where the metallized coating is considerable in relation to the wall thickness of the parent metal, further action, after normal cooling, can be sufficient to affect dimensions or even distort an accurately ground surface. A recent case, under the author's supervision, involved the metallizing of a large number of cylinder-liners externally. The first few were checked for tolerance (+0.00025 −0.00025 in.) and were well within limits with no ovality. Three days later they were rechecked and found to be oval +0.0005 −0.001 in., with room temperature approximately the same. These liners had shrunk further and distorted after grinding, and it was attributed to the fact that they had been ground as soon as they were cooled. When a time lag of two days was interposed between spraying and grinding, this trouble was eliminated. During the two days following metallizing the "dead" note originally given by a piece of sprayed high-carbon steel changes gradually to a bell-like tone which

Fig. 13 Metallizing journals of Diesel-engine crankshaft

is suggestive of some internal process continuing beyond the cooling-out stage. The subject is an intriguing one and has been engaging the author's attention for some time, but it is not anticipated that it will lead to any conclusions affecting technique, other than the already recommended time lag in connection with thin shells.

BUILDING UP MACHINERY PARTS

Building up machinery parts by metallizing covers such a wide range that it is convenient to list a few classes of work connected with marine engineering.

Restoration of Worn Components

Restoration to plan size is the most commonly undertaken class of work, and the examples are so numerous as to make the selection of a typical case difficult. The selection of a crankshaft (Fig. 13) is done because there have been more crankshafts reconditioned by metallizing than any other single component within the author's knowledge. The total number in Britain alone is probably in the region of 50,000, and although they have mainly been small ones, quite a number of large Diesel crankshafts have been metallized successfully. They provide an excellent example of restoration to original size with elimination of the necessity for undersize bearings and provision for retreatment of the original shaft many times. Some years ago the Admiralty produced an excellent specification for the reclamation of crankshafts by metallizing and this has been the basis for much of the similar commercial work also undertaken in this country. It is not unusual to find that a metallized crankshaft bearing will outlast the standard article, and this is not surprising both on account of the oil-retaining properties of the sprayed metal and because crankshaft materials are often selected on account of their forgeability and toughness, rather than exclusively for wearing properties.

Metallizing Oversize

To extend the life of a mating part metallizing oversize is frequently resorted to. An example is found in building-up piston and pump rods oversize so that the gland may be bored to suit instead of requiring replacement or rebushing. Quite apart from the economic considerations building up oversize is regularly practiced for such items as piston valves, while shortages of labor and materials often dictate that it shall be employed in cases where standard sizes would normally be used. Pistons for all classes of engines are regularly metallized oversize. Figure 14 shows a rather different type of crankshaft reclamation work in which damage to areas other than journal bearings is being rectified by metallizing.

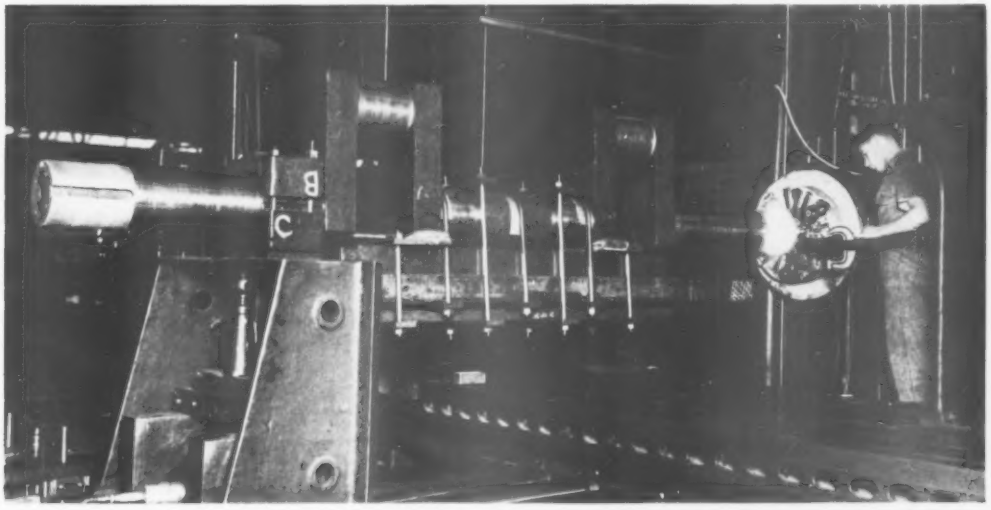


Fig. 14 Each end of a press crankshaft being sprayed with steel after damage by failure of keys

This figure shows a crankshaft set up in a horizontal boring machine at the works of Messrs. Vauxhall Motors, Ltd., Luton, being metallized with 77 lb. of high-carbon steel at the ends where the double keys had sheared and torn the surface. The driving gears were bored true but oversize and the shaft built up to suit. Owing to the very great swing involved, no lathe large enough was available and the complete work of machine preparation, spraying and finish-machining was undertaken in the boring machine. For spraying, the shaft with temporary balance weight was chucked at one end while the other end was carried in an improvised pedestal bearing as shown. For preparation and finishing, the job was packed up to the requisite height on to the carrier and the tool held in the chuck. The interesting aspect of this job is that it was undertaken twelve years ago as an emergency repair, with little confidence that it would do more than save an immediate hold-up on production. In fact, it is still operating satisfactorily and illustrates the point that the vast majority of those engineers who have accepted metallizing originally only tolerated it as a temporary expedient and have since been forced by experience to embrace it as sound reclamation practice. Perhaps more important, however, is the fact that in such work as this, the distortion by welding, which was the only practical alternative, would have risked damage beyond repair. In any case it would probably have necessitated machining all bearings true, and no local facilities for remachining the crankpins existed. Considerations such as this form an excellent introduction to a cold process.

Material and labor shortage may often dictate this method of "oversize" reclamation. It is also sometimes employed in instances in which no reduction of "core-strength" of the member to be built up could be permitted. Removal of metal to allow the minimum permissible thickness coating can in this way be eliminated, but even so, it is good practice to ignore any possible added strength due to the deposited metal. In all metallizing reclamation the engineer responsible should decide whether the component is strong enough for service without making any allowance for the strength of the coating.

Metallized Inserts

These are chiefly employed to permit a more valuable metal to be used only on that part of a component in which its particular properties are required. Both manufacturers and repairers take advantage of metal spraying for this purpose. Figure 15 shows an excellent production application in the practice of G. and J. Weir and Co., Ltd., who line heavy-duty pump barrels with a thick nickel coating. This combines corrosion resistance with excellent wearing properties, whereas it would, of course, be economically impossible to produce the pump barrel completely in nickel, and normal plated deposits would be inadequate to allow for subsequent remachining when worn. Inserts are frequently metallized so as to form sleeves on shafting, and especially mild steel pump spindles which are given a

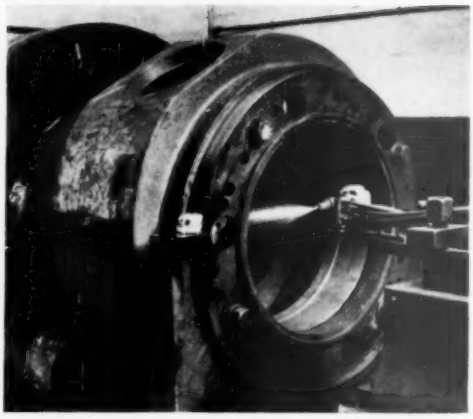


Fig. 15 Pump barrel being lined with sprayed nickel

stainless steel or Monel-metal coating on areas subject to corrosion. Circumstances in repair work can sometimes make metallizing the only possible method of repair, because a sleeve could not be fitted, e.g., a section of a shaft between two collars.

Remedying Machining Errors

An argument frequently put forward against the wider use of metallizing for this purpose is that once the machine shop people know of its existence, they may become careless in the certain knowledge that mistakes can be rectified. Although this implies confidence in the process, it does so in a negative manner, which might react unfavorably to the wider use of the metallizer. The author has investigated the suggestion in three machine shops and statistics in each case have revealed that the incidence of careless errors has tended to decrease after a spray-gun has been installed for reclamation. It is believed that this is largely due to the fact that metal spraying a machining defect gives much greater publicity to the error than does the making of a new part. At any rate, some hundreds of machine shops, in Great Britain alone, include a metallizing gun in their equipment, using it as a "putting-on tool" with the same confidence that they show in employing an orthodox lathe tool. The classes of work include not only shafting, but bores and internal ball-race housings and flat surfaces. It is not usual to build up screw threads by metal spraying, since, in general, the shear stress on the bond is too great and in any case sprayed metal is not very suitable for this class of loading owing to its structure. Much the same may be said of the actual working faces of ball and roller races, in which the respective point and line contacts impose too great a stress trying to force the particles of sprayed metal apart. It is true that some ball and roller races have been successfully built up by metallizing, but only in cases of very light loading, with the exception of work recently carried out by the spray weld process.

The suitability of spray welding to carry heavy

localized loading is due both to its hardness and to the fact that the heat treatment results in the sprayed particles flowing together so that the coating can no longer be regarded as a regular sprayed-metal deposit. For press fits and shrunk-on collars, sprayed metal, particularly if loaded with oil or colloidal-graphite, exhibits considerable resistance to "fretting-corrosion," that is to say the type of corrosion which is believed to result from the slight relative movement of two parts, one of which is subject to severe alternating stresses only partially passed on to the second member by virtue of the tightness of the fit. A gear wheel shrunk on to a crankshaft is an example. Sprayed metal itself, when forming a sleeve on a shaft—a crankshaft again being an excellent example—might well be expected to exhibit this phenomenon, but it has only been found on one occasion by the author, and the part was a thick coating on the nonlubricated end of a large industrial crankshaft, which was being examined after many years service (it had been prepared by blasting before any of the later surface-preparation techniques had been devised), and was comparable with what might be expected of a shrunk-on sleeve.

It is believed that by any of the other methods of mechanical bonding outlined in this paper, the keying effect is sufficient to prevent relative movement, even the microscopically small movement that can give rise to this form of corrosion, so that such vibrations and stresses as occur in the parent member are passed on to the coating. This matter is not merely of academic interest, since fretting or rubbing-corrosion can be a factor in giving rise to such stress concentrations as may ultimately cause failure by fatigue. While there remains room for much more useful work to be done on this aspect of coating parts subject to alternating stresses, it is encouraging to note that all the evidence of metallizing work during the past fourteen years appears to indicate that the process combats fatigue rather than encouraging it. Referring to Table 3 comparing bond strengths it is worthy of note that blasting stretches a surface in such a manner as to render it less liable to fatigue than a similar polished surface, and this even though a sharp abrasive be employed.

Oil Absorbent Bushes

These may be formed either by lining conventional bushes internally by spraying or may be manufactured entirely by metallizing. Babbitt metal is generally employed as the actual bearing metal and the method of manufacture of complete bushes by metal spraying is as follows. A very slightly tapered and undersized mandrel is cleaned and "dulled," but not roughened, by blasting. Babbitt metal is then sprayed over the mandrel to the requisite thickness, usually 12 to $^{15}/_{1000}$ in. but with the thickness compensated for the mandrel taper so as to finish parallel. Thereafter, the spraying is continued to give a wall thickness of from $^{1}/_{8}$ to $^{1}/_{4}$ in. with whatever metal may be required for the bearing shell, steel, bronze, aluminum and even magnesium having been employed for this purpose successfully. Thereafter, the outer surface is turned to finished dimensions and the bushes parted off, it only remaining necessary to reamer the bores parallel (located by the perimeter) to complete the machining. Before putting such bushes into service they are impregnated with oil containing colloidal graphite by dipping, or, if maximum absorption is required, by subjecting to a vacuum followed by oil under pressure. Bushes of this kind are economical to manufacture and are particularly suitable for inclusion at points where lubrication may be neglected by reason of inaccessibility.

Casting Faults

These are not always detected before it is too late to replace or uneconomic by reason of considerable machining work having been carried out. The informed engineer will in such cases wish to consider whether the defect can be remedied by metal spraying, but will have well in mind that metallizing does not substantially strengthen a casting. Having decided that the part has the requisite strength he will know that metallizing can be employed for the following purposes:

(*a*) Building Up Where Undersize: Provided that the bond between the coating and the casting is not subject to considerable shear-stress, nor the resulting surface liable to impact or excessive localized loading the process is as previously described.

(*b*) Sealing Porosity in Castings: This may at first sight seem contradictory in relation to the claims made for the oil absorbing properties of sprayed metal, but not so when it is realized that the porosity of the coating is a function of the thickness. The paths through sprayed metal become increasingly devious as the thickness increases. Furthermore, by decreasing the distance of the gun from the work, the incidence of welding between particles increases—and slight preheating of the casting (insufficient to cause oxidation) can be used to exaggerate this until porosity is eliminated.

(*c*) Cracks in Castings: These can often be temporarily, and in some cases permanently, prevented from leaking even under considerable pressure. The technique of repairing cracks, except in cuprous alloys, has been greatly improved by the invention of Sprabonding.

(*d*) Unsightly Blowholes: These can be sprayed with metal matching the casting, and when occurring on a working surface can, by careful selection of a material giving an equivalent wear-resistance, be made to render an otherwise useless part quite serviceable.

Metallizing Patterns

Perhaps the chief use of metal spraying in connection with patterns in ship repair work has been to apply quickly the necessary machining and shrinkage allowances on actual castings which have to serve as emergency patterns. The parts requiring added metal are cleaned, preferably by blasting, but sometimes only by

rough filing, and a coating of zinc applied to the necessary thickness. This is particularly convenient on parts which, owing to their shape, cannot readily be enlarged for use as a pattern by the usual means. Additionally, patterns for repetition work can be made undersize of wood and then metallized, with the advantages of lightness in use, easy alteration by spraying metal to thicken a webb or alter a curve, and elimination of warping.

Emergency Repairs

Ship repair work is so frequently a matter of urgency that many of the classes of work already mentioned fall within this category at some time or other. The work on the port main turbine casing of H.M.S. *Verity*, described earlier, is an example, and another instance occurred on the same vessel which illustrates how well metallizing is adapted to eliminate delays in shipping. Figure 16 shows the top and bottom halves of *Verity*'s port circulating pump, damaged by an underwater explosion at the same time as the other major defect. The pump, originally manufactured in France, had no patterns or spare parts available and was so distorted that the author could get his fingers between top and bottom casting flanges. The bearing housings were pushed upward $^{5}/_{16}$ in. and the impeller-boss axial clearance increased by $^{5}/_{8}$ in. Time was the essence of the repair, and metallizing solved the problem. A 140-lb. weight of bronze was deposited over the "low" surfaces, and the two castings remachined to original dimensions with completely satisfactory results.

The chief factors favoring metallizing for emergency repairs are:

1. Speed with which the work can be carried out—as much as 20 lb. of steel or much larger quantities of lower melting point metals can be deposited in an hour, so that it is quicker than welding to apply, and much less machining allowance is necessary by spraying.

2. Risk of heat damage is eliminated so that parts can often be metallized *in situ*, e.g., a turbine bearing can be metallized with the rotor in position without fear of distortion, and the same applies to sealing a crack in a Diesel engine cylinder block water jacket. Figure 17, showing the metallizing of a turbine shaft *in situ*, is typical. Figure 18 formed the subject of an *in situ* repair on an ammonia compressor and, although similar to marine engineering applications, this work was carried out in a London brewery under the guidance of the chief engineer. The gland cover was removed so as to expose the shaft which was metallized with stainless steel and reground with a portable tool post grinder successfully without removing the shaft from the compressor.

3. The most appropriate metal can be selected without reference to its fusibility to the parent metal, so that a limited variety of metal wires will cover all likely classes of repair work.

4. It permits using worn and oversize mating members with consequent advantage.

5. Metallizing is often the only possible means of salvaging a worn part, and yet it involves no special plant with the exception of the hand gun provided an adequate supply of compressed air is available on site.

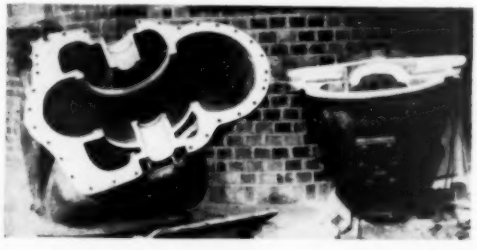


Fig. 16 Top and bottom half castings of a circulating pump built up with 140 lb. of bronze on flanges, bearing housings, etc.

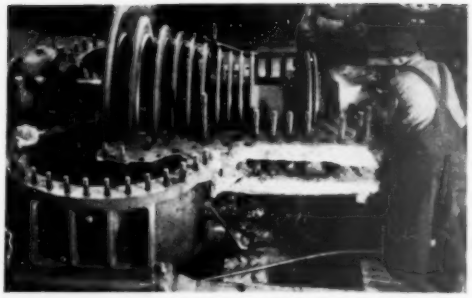


Fig. 17 Turbine shaft being repaired in situ

General Marine Applications of Building-up Work

The ideal example of metallizing, and one which is not only well proved, but particularly easy to accomplish, is building up an unbroken periphery, such as a journal bearing. Whereas it takes approximately three days for an operator to be intensively trained in all classes of building-up work (provided he is able to use a

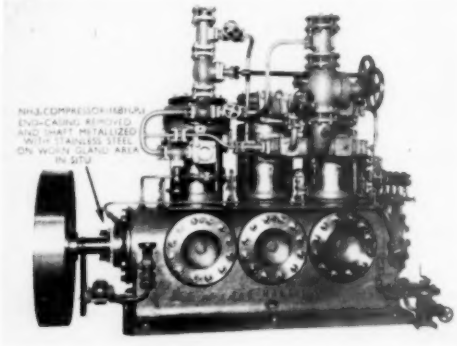


Fig. 18 Ammonia compressor repaired without dismantling

lathe), in a single day a man of average intelligence will be quite capable of learning how to build up worn journal bearings faultlessly. The manufacturers of metallizing equipment train operators, although with such a book as the *Metco Metallizing Manual* in his hands, a foreman can quite easily train a machinist in preparation, spraying and finishing, beginning with the straightforward reclamation of bearings.

Propeller shafts are perhaps the simplest class of work on which to begin, and are well worth doing, not only on account of the longer service obtainable from metallized journals, but because such shafts do not readily lend themselves to welding on account of distortion. Steel or bronze shafts, large or small, at the A-bracket bearing, stern gland or any plummer block bearings, are all equally suitable. Figure 19 shows two guns simultaneously spraying a propeller shaft journal.

Fig. 19 Propeller shaft journal being metallized in a lathe

The period just prior to D-Day found metallizers busy around the southern coast of England making good the ravages of corrosion on the tailshafts of landing craft. With salt water as the electrolyte and steel shafts against bronze bearings, many of these craft had stood in creeks and rivers long enough to "rust-up solid," and but for the metal spraying process might have presented a major problem. Fortunately, it was found possible to salvage these shafts well inside the time limit.

The turbo-pump shaft, illustrated in Fig. 2, is typical of repairs to auxiliary machinery, which, of course, include also all types of pump and piston rods. Where corrosive conditions are encountered, stainless steel and pure nickel are the general choice, and as a rule stainless steel is favored for a rotary part and nickel when reciprocating motion is involved. Stainless steel is not recommended where it would be in contact with leather packing; it is, however, one of the metals chiefly employed on shipwork, so that a word as to its properties in relation to the solid metal may be worthy of inclusion here. In order to retain its quality of resistance to corrosion, stainless steel must have a high finish, such as is imparted by grinding. The characteristic matt finish in the sprayed condition is, therefore, not the most suitable type of surface to withstand corrosion and must be corrected by turning or grinding. It is worthy of note that the time taken to heat, atomize, deposit and cool the metal below the critical temperature during spraying is insufficient to permit migration of carbon to the grain boundaries, so that, unlike welding, there is no risk of "weld decay" when spraying any of the wide range of austenitic steels. A material developed from the well-known 18–8 stainless steels is often employed where corrosion resistance is all important. High-chromium steel known as "Metcoloy 2" is by far the widest used metal for building up worn parts which, in addition to requiring reasonable resistance to corrosion, must be particularly hard wearing. Pump rods, hydraulic rams, deck and dock machinery parts are regularly metallized with this material with excellent results.

Pistons have recently received more attention from a metallizing point of view due to shortage of supply. In general it was considered previously that only really large pistons were worthy of treatment, except that the skirts of small pistons were sometimes metallized to take up piston slap. Ring grooves are not usually metallized, since as new rings are usually called for it is easier and cheaper to make the new rings wider than the original and machine the grooves oversize. The lands between the grooves on the larger pistons are now regularly sprayed, a shoulder being left at each end of the land when carrying out machine preparation.

Some experiments with the reclamation of aluminum and light-alloy pistons are not without interest. These can be built up with high-carbon steel with only negligible increase of inertia forces, and have very good wearing properties. Tests suggest less cylinder or liner wear than when the "solid" aluminum or light alloy pistons are employed. Metallizing has also been employed to rectify piston top damage, and within pistons, bands of copper have been sprayed to conduct heat away from undesirable hot spots.

The more difficult problems connected with building up by metallizing relate to the treatment of flat surfaces or spraying internally in bores. In general these classes of work require more particular attention to preparation so as to anchor sufficiently well to take care of contraction stresses. Wherever possible spraying of flat surfaces is continued over edges, and if a heavy coating is required it is advisable to Sprabond the surface before applying the coating material. Internal work, of $3^1/_2$ in. diameter and above, can generally be carried out satisfactorily, but where spraying is all from one end of a small bore, then unless extension equipment is used in connection with the gun, it is not practical to spray the

bore to a depth greater than the diameter, or twice the diameter, if spraying can be carried out from each end. The reason is that the spray should strike as nearly as possible normal to the surface, but in no case at an angle of less than 45°. Where greater depths are required, the front of the metallizer is extended by a tube, and a deflecting nozzle, known as an angular air cap is employed to deflect the spray sideways on to the walls of the bore being treated.

Fig. 20 Repair of oversize bore in sternpost

Figure 20 illustrates internal work—a recent instance of remedying clearance between the stern-tube and bore of the stern-post on a Gosport-Portsea ferry steamer. The 9-in. diameter hole was Sprabonded and metallized with $^{15}/_{1000}$ in. thickness of zinc, scraped true and the stern-tube pressed back in place in less time than would have been required for fitting "shims" and the result was much more reliable.

PROTECTIVE COATINGS

The Theory of Corrosion

In order to be in a position to select a suitable material to resist particular conditions of corrosion, it is necessary to have at least an elementary conception of the theory of corrosion, and in addition to understand the structure of sprayed metals so that due allowance can be made for its influence upon the problem. So many factors affect the rate of corrosion between metals—and some of these factors are so elusive—that it is good practice to confine actual work to classes for which there are successful precedents or, alternatively, to carry out tests under circumstances which as nearly as possible duplicate the conditions of service. Only by such means will the marine engineer be able to apply corrosion resistant coatings with confidence, and even then if his opinion is based on laboratory tests rather than actual experience, results may not justify expectations. Fortunately, however, we now have a wealth of experience on which to draw, so that reference to the theory of corrosion is made mainly as a matter of interest though it can be useful in the selection of likely metals for a test. Corrosion problems in connection with metal-sprayed coatings commonly involve two metals only, so that it is worth while considering the effect that one metal may have on another. It is possible to arrange metals in order, based on their tendency to set up galvanic corrosion on each other. (This is not quite the same thing as the electro-chemical series, though similar.) The list begins with materials which are the more readily attacked, or what is known as the anodic end of the series, and continues in order of merit until it ends in the more noble or cathodic materials which themselves derive protection from contact with the more corrodible metals higher in the last.

*Galvanic Series**

Corroded end (anodic):	Magnesium
	Aluminum
	Duralumin
	Zinc
	Cadmium
	Iron
	Chromium iron (active)
	Chromium-nickel-iron (active)
	Soft solder
	Tin
	Lead
	Nickel
	Brasses
	Bronzes
	Nickel-copper alloys
	Copper
	Chromium-iron (passive)
	Chromium-nickel-iron (passive)
	Silver solder
	Silver
	Gold
Protected end (cathodic)	Platinum

The metals are grouped and those in each group do not possess any strong tendency to set up galvanic corrosion with each other. Contact between metals far apart in the list tends to corrode the one in the higher group. Circumstances may cause metals to change their position in this list, but usually only within a group, i.e., not between groups. The chromium-irons and chromium-nickel-irons, however, are an exception

* From *The Corrosion Resistance of Metals and Alloys*, by McKay and Worthington.

in that they take one or other of the positions indicated according to oxidizing conditions, acidity and chloride in solution. The list as arranged, however, is correct for a large number of dilute water solutions including sea water and both weak acids and alkalis.

Sacrificial Action of Anodic Coatings. All marine engineers are familiar with the protection afforded to steel by the introduction of zinc slabs in intimate contact with the steel, and as near as possible to any corroding influence. The degree of protection varies inversely with the distance from the zinc slab, so that if the steel could be covered all over with a large number of very small zinc slabs, it might be anticipated that whereas the zinc itself would be attacked, complete protection would be afforded the steel. This, in fact, is just what happens when steelwork is zinc sprayed on all exposed surfaces. The commonest material requiring protection by metal spraying is, of course, steel, denoted in the galvanic series by its main element, iron. Anodic protection of steel is afforded only by those metals appearing higher on the list, and aluminum, zinc and cadmium are all employed for this purpose, although cadmium to a much lesser extent on account of its high cost. It may at first sight appear absurd to use a metal which will corrode in order to protect another metal. The explanation is that while the initial attack on exposed zinc or aluminum will be rapid, the oxides which form during the attack stifle further action until they themselves are either mechanically removed or dissolved so as to expose more of the protecting metal. Protection may thus be truly described as being afforded by the zinc or aluminum oxide, respectively, the balance of metal remaining in the coating acting rather as a reservoir to supply further oxides to replace losses. It is unfortunate that rust—the oxide of the commonest metal, iron—has no such advantages, but it is an easy matter to replace it with a surface which will behave in the manner described.

It has already been noted that sprayed metal is porous, but this provides no great difficulty when using the coatings to give anodic protection because the formation of the zinc or aluminum oxide seals the pores and prevents exposure of the steel base. While aluminum may claim certain advantages, especially in industrial atmospheres, because its oxide is not so readily soluble in rain water, zinc is the metal recommended for protection of steel against sea water corrosion both for immersion and for very salt atmospheres. For immersion in hot fresh water—particularly hard water—aluminum is the better coating, although it gives disappointing results with some soft waters. Zinc, however, is not satisfactory in any water at temperatures exceeding 125° F.

Anodic coatings fulfill two useful functions in service, after initial attack has occurred; they protect a surface mechanically (as indeed most coatings do), and in addition sacrifice themselves in such a manner as to continue to give protection. Even if damaged, as by scratching, the oxide tends to bridge any gaps, and if too great to be bridged the very presence of the anodic metal in close proximity and intimate contact will regard the corrosion rate of the exposed surface.

Cathodic Coatings. Cathodic coatings are sometimes employed for protecting parts from corrosion. Because the average engineer has a working knowledge of how metals behave in the "solid" state, he is apt to expect too much of cathodic metals when sprayed. This is largely due to the porous nature of sprayed metal and unless considerable thicknesses of cathodic metals are employed, coatings fail by reason of attack on the parent metal through the pores of the sprayed coating. Reverting again to the galvanic series, it will be noted that there is an extensive list of metals below iron which are all cathodic to iron—some indeed, such as copper, are pronouncedly so. Consider, therefore, what happens when a thin coating of copper is sprayed on iron or steel. The electrolyte, which may be rain water, sea water or perhaps something more corrosive, will find paths through the copper by which it can attack the steel. Since the steel is anodic to copper, the copper will tend to be protected by its contact with the steel, and the steel itself may be the more rapidly attacked. The sacrificial action so laudable in zinc or aluminum with respect to steel is the source of weakness when the steel becomes the anode and is itself sacrificed. Cathodic coatings if too thin and porous, or having pinholes, scratches or other means of exposing the anodic base material, may accelerate corrosion rather than retard it. Once this basic principle is properly understood, it follows naturally that cathodic coatings such as stainless steel, tin, lead, nickel, bronze, etc., must be rendered impervious to the corroding influence either by the thickness of the coating employed when applied to machine element reclamation work, or by sealing the porosity in thinner coatings—a course frequently resorted to when applying coatings to resist corrosion.

Sprayed tin, which is quite an expensive metal, requires approximately $^{15}/_{1000}$ in. thickness to prevent access by most liquids, and even then must be scratch-brushed with a stiff wire brush to close mechanically the pores as far as possible. With liquids of low viscosity even thicker coatings are necessary. However, even half this amount can be used satisfactorily if the pores are originally sealed by spraying, brushing or dipping with a suitable sealing medium to withstand the particular conditions of service. A type of bakelite varnish is sometimes employed for this purpose, while on other occasions chlorinated rubber may prove more suitable. Sprayed lead is often similarly sealed. It is less usual to seal nickel, copper and their alloys, as these are largely restricted to building up worn parts where the coating thickness will be sufficient to prevent contact between the base metal and the electrolyte but where excessive pressures are anticipated, as with hydraulic rams, linseed oil mixed with 5% by volume of cobalt liquid drier is found suitable.

Coating Thickness. It will be obvious from the foregoing that a great deal depends upon the thickness of coating employed and the total life of anodic coatings is very largely proportional to their thickness. Alu-

minum and zinc are generally applied in thicknesses varying from 0.004 to 0.012 in. according to the conditions of service and life required. With cathodic coatings the thickness is more critical in that below a certain minimum, which will vary according to circumstances, such coatings are useless by reason of their porosity while above that minimum, except for a reasonable margin of safety and allowance for mechanical loss by abrasion, if any, additional life may not be achieved by increasing the thickness. Before using cathodic metals for coating work, therefore, one is well advised to consult suppliers of equipment for their recommendations until sufficient experience has been gained within one's own particular field. The measurement of thicknesses of nonmagnetic coatings on to magnetic bases and, of course, more particularly the commoner coatings of zinc and aluminum, are generally determined by either an electric layer thickness meter or a magnetic meter which respectively interpret electrostatic capacity of a small area of the plate or, similarly, the interference of the magnetic field from a small permanent magnet, so as to give the mean thickness of the part of the coating being tested in thousandths of an inch. However, most commercial work is carried out very uniformly to the requisite thickness by weighing an amount of wire for a given area until the operator has sufficient practice in applying coatings to know when he has deposited the requisite amount. Uniformity of thickness is achieved much more easily than might be anticipated. The ribbon of metal deposited in a single pass of the spray gun tends to be thicker toward the center than at the extremities, so that parallel strokes should be applied, each successive ribbon overlapping the previous one by approximately one-third. With modern equipment it is usual to arrange the speed of movement of the operator to coincide with a deposition of 0.002 in. thickness for each pass, and for subsequent layers to be applied by making passes at different angles. Where two coatings of 0.002 in. each are to be applied, the second is applied in a direction at right angles to the first. If three coatings are used it is convenient to make the angle 60° between each coating. It follows that the greater the number of coats applied, the more nearly will uniformity be achieved. For flat surfaces $^1/_4$-lb. zinc or $1^1/_8$-oz. aluminum will produce a coating of 0.005 in. thickness and pro rata. On narrow sections and on edges due allowance must be made for losses, but in practice it all becomes much easier than its description may imply. If measurement of thickness is read by a micrometer, then additional allowance must be made for the characteristic matt finish, so that the average thickness is somewhat less than the apparent thickness read by such means.

Finishes Applied Subsequent to Spraying

Painting. The matt surface of sprayed metal renders it very suitable for bonding paint and, unlike galvanizing, no "weathering" is called for since no acids have been employed in producing the coating. The success of the painting will largely depend on the choice of paint, which must be suitable for the matt surface and selected as appropriate to the particular metal of the coating. The former consideration applies to all sprayed metal coatings and, in general, it is important that the paint must not be so thin that it will be absorbed in the pores of the sprayed metal or so thick that it will bridge across the "valleys" in the matt surface. Quick-drying paints should be avoided, except when a very thin coating is to be employed, e.g., a lacquer finish for appearance. When paint is to be applied to sprayed zinc it is recommended that zinc chromate or iron oxide-zinc chromate paint be used, and these should preferably be in long oil varnish vehicles or those made with bakelite and glycerol-phthalate resins. Bituminous base paints are sometimes used but are not generally regarded as being equally satisfactory. Red lead must not be used with zinc coatings nor must antifouling compounds be employed with them since most of these contain metallic copper which would result in rapid corrosion. Paints which are suitable for use on zinc coatings are generally suitable for aluminum, and in addition pigments such as aluminum, iron oxide, red lead, titanium oxide and zinc oxide held in durable vehicles may be used on top of sprayed aluminum.

Coatings Used to Support a Sealing Medium. Reference has already been made to sealing metal-sprayed coatings, but there is another aspect of this which involves the use of the sprayed metal largely as a vehicle to hold a second material. It has been found, for instance, that protection of tanks to hold certain edible oils is afforded just as much by an extremely thin coating of, say, $^2/_{1000}$ in. thickness of aluminum as by a coating many times thicker, but only if, immediately after spraying, the coating is saturated with the particular oil which it is intended to carry in the tank. The sprayed metal holds the oil in its pores by capillary action so that even when the tank is emptied a layer of oil will be interposed between the atmosphere and the mild steel tank, so preventing corrosion. Another somewhat similar example is the use of a very thin coating of zinc or aluminum, followed by brushing, spraying or dipping with a solution of zinc chromate. The zinc chromate held in the pores inhibits corrosion so long as it remains present.

Steel Hulls

Reverting to Fig. 1 showing the zinc spraying of a ship's hull this work proved unsatisfactory. Because the vessel's bottom had previously shown only negligible corrosion it was not zinc coated. Thus the only wetted zinc was a narrow band in the region of the water line, forming a relatively small anode with metallic and liquid paths to the large cathode formed by the steel bottom. Rapid attack on the ship's sides first destroyed the paint and then consumed the zinc, though the comparatively dry zinc coating on decks and superstructure was scarcely damaged. Thus, failure to appreciate the factors governing corrosion made it

necessary to respray the sides and eventually to metallize the ship's bottom although it had previously not been thought necessary. Some of the details already discussed can now be applied to this important application of the process. The recommended procedure is as follows:

1. Where small vessels are concerned considerable advantage may be derived from carrying out the work under cover when possible because otherwise weather conditions can cause delay.

2. It is necessary to rig up staging for the work and the author has found it well worth while rigging tubular scaffolding so as to eliminate delays in moving from one part of the hull to another. This is particularly advantageous in that it permits blasting to be carried out in one area and then continued in a second area some distance away while metal spraying can be carried out immediately after each section has been blasted without holding up further blasting work.

3. Tarpaulins are arranged around the scaffolding so as to form cubicles to minimize risk from the flying abrasive.

4. A sharp angular flint grit or other sharp sand of between 12 and 20 grade is employed. Steel grit would be quite effective, but there is usually so much loss of abrasive on this class of work that it is much cheaper to employ a suitable sand. Sea sand is smooth and unsuitable.

5. Each part of the work to be treated is blasted to a rough and silvery finish, and if existing rust is very considerable it may prove economical to carry out preliminary chipping, or in some cases flame cleaning, though the latter is not usually necessary, and in any case only in certain comparatively small localized areas.

6. Zinc is used for ship's hulls because it is superior to aluminum for immersion in sea water. It is recommended that a hull be metallized all over since leaving part untreated may call for too much "sacrifice" by the zinc. In any case all the immersed surface must be treated.

7. The spraying of each section must be carried out immediately after blasting. It is not satisfactory to leave an area in the blasted condition overnight. The spraying should keep time with the blasting. The speed of blasting is dependent on the volume of compressed air available. Modern metal spraying equipment, which can deposit up to 55 lb. of zinc per hour permits metallizing at a rate exceeding the highest blasting rate.

8. Where an area must be left for an hour or two zinc should first be applied lightly over the whole surface to be left and the work completed as soon as possible thereafter. Even a thin zinc coat will prevent early damage to blasted surfaces, otherwise the blasting should be carried out a second time.

9. The recommended thickness of zinc for steel hulls is $^{10}/_{1000}$ in. and this represents the use of $^{1}/_{2}$-lb. zinc wire per square foot.

10. Vessels having steel propeller shafts and cast-iron propellers may have the exposed part of the shaft and the propeller coated with zinc similar to the treatment of the hull, but vessels fitted with bronze propellers and shafts must have such parts coated with Monel metal. The thickness of Monel metal on the bronze shaft and propeller should be 12 to $^{18}/_{1000}$ in. when finished. If the propeller shafts are drawn for this purpose then the spraying of the shafts can conveniently be carried out in a lathe and they can be finished-machined so as to form a sleeve of Monel metal similar to the building-up work described earlier. If this is not possible, then the preparation of the shafts and of the propellers needs much greater care than is the case with the work on the ship's hull; very considerable roughness of the base material being required to make a satisfactory bond for the Monel metal. These remarks apply particularly to the edges of propeller blades, and it is safer to employ either Sprabonding or fuse bonding on the shaft and propeller unless a very high standard of blasting can be achieved.

11. The subsequent treatment of the hull is, of course, as described in the section dealing with painting of zinc coatings, particular reference being made to the remarks concerning the use of antifouling compounds. Sprayed zinc itself has some antifouling properties in cold waters.

12. Generally it should be observed that the life of the zinc coating is very largely proportional to its thickness, so that areas of maximum attack as, for instance, the "wind-and-water" area just above water level may have a slightly thicker zinc coating, or any other part of the vessel where corrosion is found to be particularly rapid. In the same way it is possible to economize somewhat on areas which experience has proved to be less rapidly attacked.

The zinc spraying of steel hulls has been carried out much more in America and certain European countries—notably Sweden—than in Great Britain, although much has been done here during the postwar

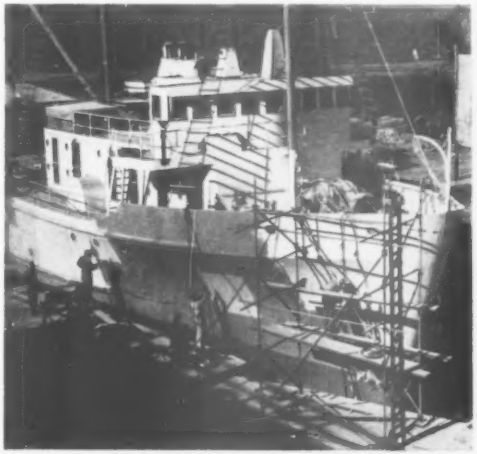


Fig. 21 American fishing vessel afloat being zinc sprayed from pontoons

period. Figure 21 shows an American fishing vessel being zinc sprayed for protection. One prewar example of sprayed zinc on a vessel impressed the author very favorably. A dredger had part of its deck metal sprayed where the action of salt water, plus abrasion by ballast falling on the decks during unloading, had very much thinned the deck plates until there was definite danger of failure. The vessel discharged ballast nightly, polishing part of the deck in so doing. The following day on putting to sea to refill with ballast the deck rapidly rusted, so that the cycle of rusting and polishing was in operation daily. It was considered at the time that zinc might not sufficiently well resist abrasion, but the comparison was not between zinc and steel, but between zinc and rust. The zinc spray was regarded as highly experimental, but it performed better than had been hoped and is still giving good service. A difficulty was encountered recently when one of a number of barges that were zinc sprayed rapidly threw off the subsequent coating of paint. It was found that the paint had been applied while the sprayed zinc surface was covered with frost, and, of course, as might have been expected, this interposed layer completely destroyed all chances of a good bond between the paint and the zinc. But this happens when paint is applied to frosted steel plates also.

Some partial failure of zinc-sprayed hulls occurred before the necessity to coat the bronze propellers and shafts with Monel metal was fully appreciated. Zinc coating the bronze parts is not a reliable alternative, since mechanical damage to the coating—a thing always likely to occur with a propeller—rapidly results in coating failure, though zinc, sealed with chlorinated rubber, has been used with some success. Similar damage to a steel hull, or indeed to a cast-iron propeller, does not have the same dire results. When the various points already made are appreciated by those in charge of metallizing a ship's hull, the process proves not only reliable but of lasting value. Figure 22 shows a large American coal barge being metallized in 1934 and the most recent reports indicated that it was still giving excellent service.

Fig. 22 Early example of steel hull being sprayed with zinc

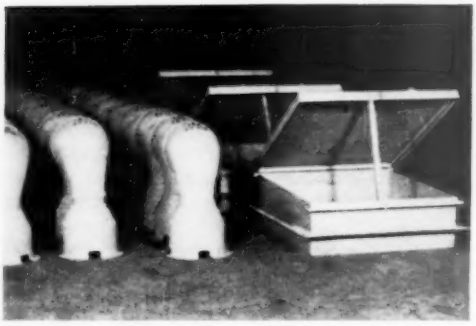


Fig. 23 Batch of cowls and hatchway covers protected by metallized zinc coating

Protection of Miscellaneous Parts

Steel tanks and holds are regularly metal sprayed. There is, however, no complete answer to such a combination as oil fuel on one trip followed by salt water ballast on the next. Where tanks are employed for one specific purpose, metal spraying usually gives adequate protection. Deck fittings are regularly treated. It is interesting to note that aluminum fittings for yachts, etc., have been given added life by spraying with high-purity aluminum, the oxidized surface so produced imparting some immunity from salt water attack. Furnace parts such as air cones for oil-fired boilers, and fire bars in coal-burning boilers have been protected against heat corrosion by spraying with high purity aluminum. Refrigeration rooms, including coils and fittings, are often zinc sprayed to prevent corrosion. The list, of course, could be extended to include most items subject to corrosion. Figure 23 shows a batch of cowls and hatchway covers protected by metallizing with zinc. Many complete steel launches have been treated in this manner, and ship's lifeboats of all-steel construction with their constant exposure to heavily salt laden atmosphere provide another excellent example of the usefulness of the process.

This paper seeks to stress both the limitations and usefulness of metal spraying in shipwork, so that those who would use it may be justifiably confident. If such knowledge sometimes enables a chief engineer to expedite a repair, or a shipyard executive to give better service to shipping, then these notes on the marine engineering aspects of metallizing will have fulfilled their purpose.

(*Discussion of this paper will appear in next issue*).

Save Steps with This Table

Portable shop table holds your welding and cutting tools

by L. W. Young

THIS table provides a convenient working surface for your welding and cutting jobs. It can save you many steps because you will have a vice, flux containers, fire bricks and C-clamps right at your elbow. You will also have plenty of room for any other tools you might need.

The materials needed to build this table, and the dimensions, are shown in Fig. 1. Cut all parts with your cutting blowpipe and then bronze weld. The table goes together easily if you complete two subassemblies first. One consists of the 30-in. length with sidepiece and angle iron brace. The other consists of the 28-in. legs with sidepiece and brace. To complete the framework, bronze weld the 39¼-in. scrap iron sidepieces and the other two braces to the subassembly. Then bronze weld stringers or joists to the facing sidepieces to provide additional support. The table top is joined to the sidepieces by continuous welding all the way around the table. Tack welds can also be used to secure the top.

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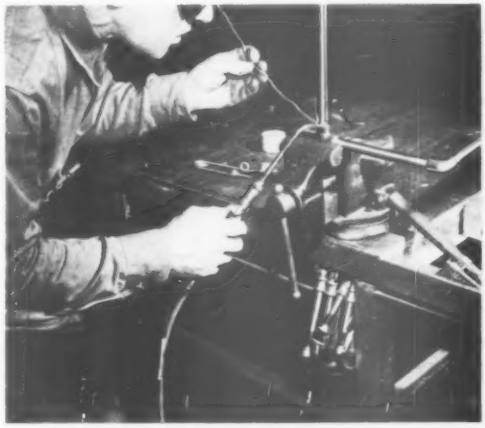

Fig. 1 Firebricks, vise and C-clamps are always at hand. You can design attachments for holding other tools, too

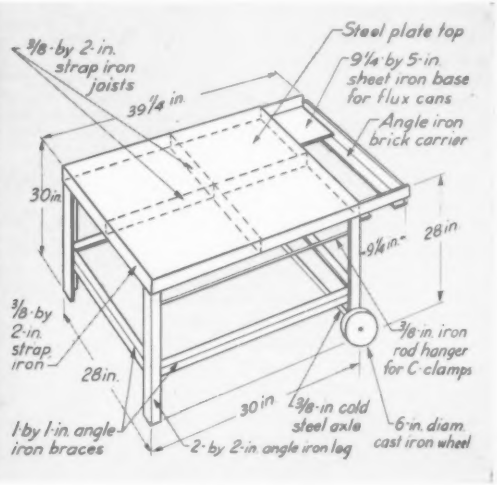

Fig. 2 A welding table like this is easy to make and easy to wheel about the shop

Provide a recess for five firebricks and one or two cans of flux by welding two pieces of angle iron between the overhanging sides. Weld one angle to the ends of these sidepieces and the other to the 28-in. side as shown in the sketch. Place a $9^1/_4$- x 5-in. piece of thin sheet iron at one end of the recess for the flux cans. The remainder of the space in this recess is used for firebricks. Put on the wheels, vice and C-clamp holder last. You can probably design attachments for holding other tools you want on hand for cutting and welding jobs.

Jig for Tacking Cylinder Girth Seams

by H. A. Huff, Jr.

IT IS not uncommon to have to join the ends of two cylinders or tubes of sizeable diameter, and as the diameter increases, the problems of aligning, fitting and clamping the parts grows rapidly. The simple jigging method sketched here takes care of the problem of concentric alignment and clamping with minimum difficulty, and also permits tacking the joint quickly and easily. Since this type of girth clamp follows the contour of the work snugly, it does not interefere with rotating the work for position welding. Longitudinal clamping can be used, when required, to maintain the required fit-up of the parts.

Fig. 1 The basic construction of a band-type circumferential jig in two halves joined and tightened by bolts, and with suitable slots for tack welding

The jig is a suitable length of strap iron, formed to a circle, provided with joints to open and close and slotted at intervals to permit access for tacking. The sections are fastened and tightened around the parts by bolts, toggle clamps, or turnbuckles at the joints. Width and thickness of the strap material, length and number of the sections, and the size and spacing of the slots will depend on the individual job. In one case, this type of jig was used on a 10-ft. diameter tank, and the strap required, in two sections, was made of $^3/_8$- by 4-in. material, with 4- to 5-in. slots 4 to 5 in. apart. Angle clips were welded to the ends of the segments, and they were drawn tight with heavy bolts. For smaller units, such as might be produced in numbers, a hinged unit with a quick-acting toggle clamp might be adviseable for faster attachment and removal.

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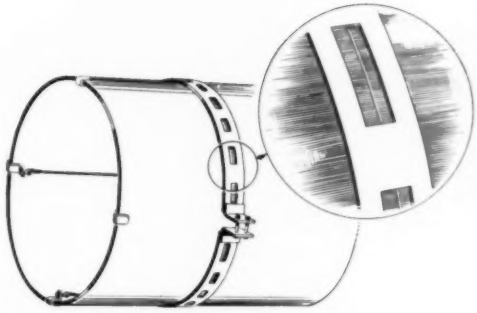

Fig. 2 The jig as it is used on large diameter tubular parts with longitudinal clamping to provide good joint contact

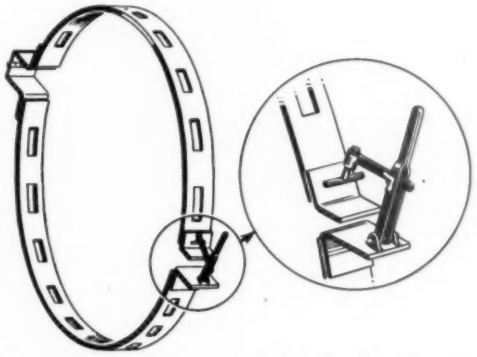

Fig. 3 A suggested way of building a quick-acting version of the jig, with one joint hinged and the other closed by a toggle clamp

In use, the parts are brought together and clamped lengthwise as required, with the strap placed around them so that the slots open over the joint. When the strap is tightened, the two circumferences are held tightly in alignment, and after tack welding the clamp is removed to permit complete welding of the joint.

Designing for Welding—Part VI

by Wallace A. Stanley

IN RECENT issues we have been discussing the basic design of projections for the use of projection welding. Shown here are a number of typical examples of how this process may be applied. In each case a "wrong" way to design the parts is given together with a better way, in order to bring out important design considerations as they affect the quality or cost of the final product.

Thus, in Fig. 1, where it was desired to weld a flange to a tube, the use of an annular flange spot welded is not as good as making the flanges in two halves and projection welding them to the tube simultaneously by direct projection welds. The reason is that the latter eliminates shunting of current shown at the left by the arrows of current flow around the tube. Note the use of elongated projections referred to in the last issue. The *two* halves cause a definite "break" in the current path, and *require* the current to flow INTO the two halves rather than AROUND the rings which is now impossible.

Figure 2 shows two methods of attaching a stud to a plate. The wrong method in this case employed projection welding, the stud being held in a die. Cost is relatively high and the weld is not as strong as is obtained by the other method. The correct projection is of the annular type shown at the right. Note the space provided around the stud for the flow of metal during welding. The stud, sticking through the plate is actually reinforced by the plate and maximum strength is obtained by putting the weld in compression when the part is assembled.

The advantage of using an annular projection weld upset in the flange of a bracket to be attached to a stamping is shown in Fig. 3. To spot weld parts like this is not only slower but also is more difficult since there is little clearance for the welding electrode. The projection welding operation, on the other hand, requires only a simple die for a one-shot operation, making all welds simultaneously.

Shown in Fig. 4 are two methods of welding a bracket to a tube. The part, if designed as in the wrong method, has to be carefully located and rigidly clamped prior to welding. In the other method, a simple die

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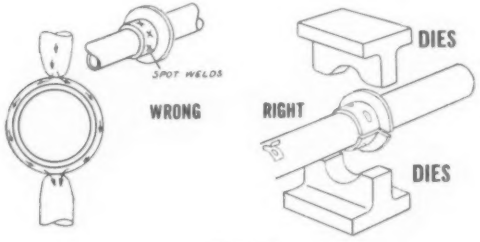


Figure 1

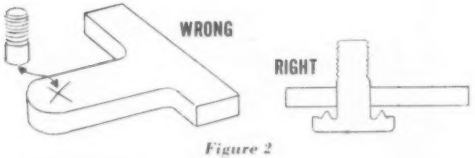


Figure 2

Figure 3

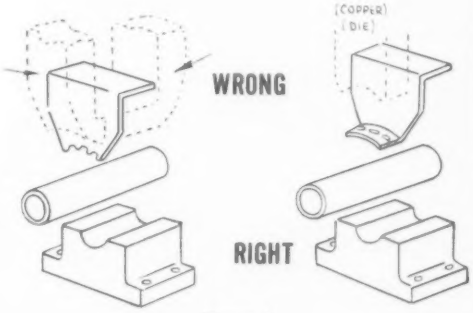


Figure 4

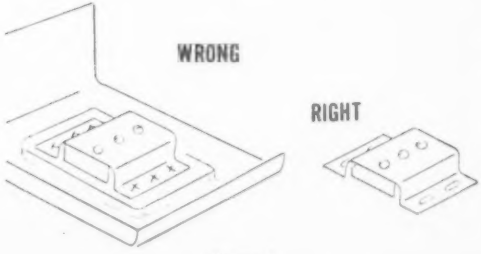


Figure 5

can be used and the part is practically self-locating and self-clamping. The extra clamping operations, both BEFORE welding and unclamping AFTER welding consume valuable production time, in addition to requiring the welding current to flow thru the stamping to reach the projections, which often results in uneven current distribution, etc. The simpler construction at the right presents a direct backup of the projections and a direct current transfer.

Another instance of the advantages of elongated projections against the use of spot welds is shown in Fig. 5. Aside from the question of clearance for the electrode, the six small, close-spaced separately made spot welds are not stronger than the four simultaneously formed projection welds. Moreover the die can be made so that the parts are practically self-locating, and the maintenance of individual tips is then eliminated in favor of a larger die surface.

Welding Galvanized Pipe

by H. E. Simkins

A LARGE southern producer of galvanized and light metal fabrications, recently completed a galvanized iron exhaust stack approximately six stories in height and 36 in. in diameter which was metallic-arc welded with Ampco-Trode 10* electrodes. Another similar string is under construction at the present time.

Welded construction was selected in preference to riveting in order to save time and metal weight. Complete riveted design was originally specified but this was changed to allow all subassemblies to be welded in the down-hand position in the shop for ease of fabrication. However, the sections were joined during erection by riveting.

These foundry ventilator stacks are fabricated from 11-gage galvanized iron and were welded with $^1/_8$-in. diameter aluminum bronze electrodes using reverse polarity, direct current.

Aluminum bronze electrodes were selected after experiments with numerous other electrodes because of the ease of application.

Aluminum bronze electrodes can be applied at relatively low amperage settings because of the lower melting point which has four distinct advantages:

1. Burn-off the zinc coating on the pipe adjacent to the weld is held at a minimum.
2. The excellent braze-welded bond secured is as strong and ductile as the base plate.
3. Undercutting is eliminated.
4. No back-up strip is required since the lower melting point aluminum bronze deposit only penetrates sufficiently to produce a small, uniform inside bead which requires no finishing.

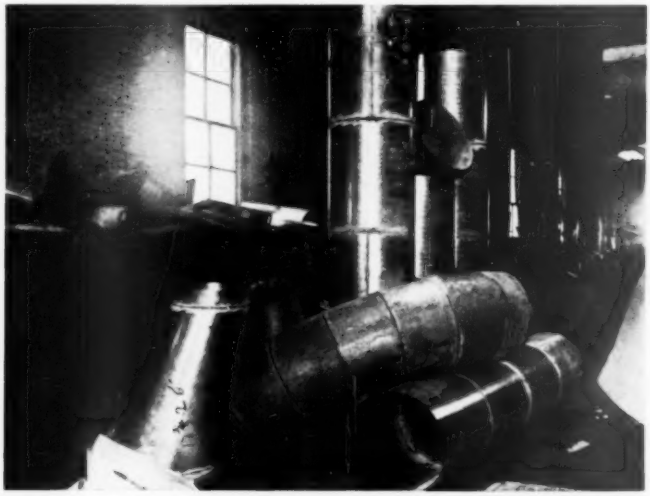
All subassemblies were positioned for welding and turned toward the welder as he held the electrode slightly off center in the direction of rotation producing exceptionally smooth welds free from surface pitting and porosity. The steel flanges were also welded to the light walled pipe using the same electrodes.

* Shielded-Arc Aluminum Bronze Electrode A.W.S.-A.S.T.M. Specification ECu Al-A.

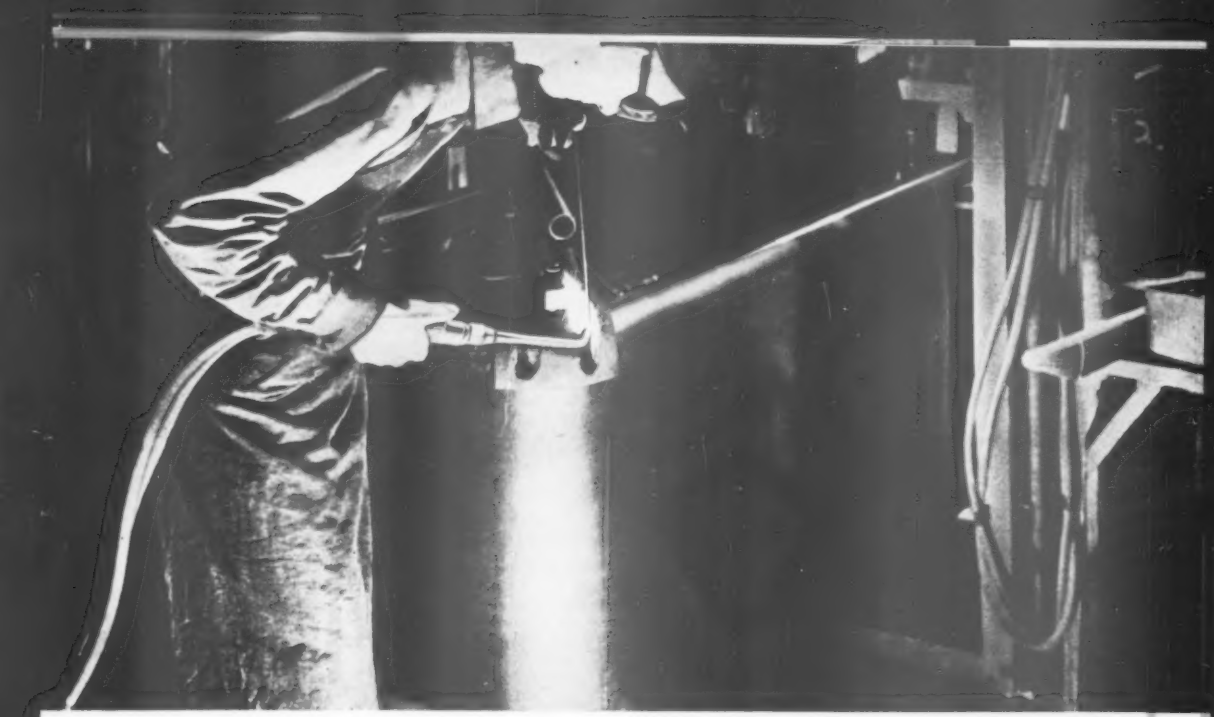
H. E. Simpkins is with the Delta Oxygen Co.

Data supplied by Ampco Metal, Inc.

Pipe positioned and rotated for quality welds



Large group of welded assemblies ready for field erection



How to Weld Sheet Steel

Part I—Oxy-acetylene welding*

Here's how to make butt, flange, and corner welds in steel up to $^1/_8$-in. thick

by K. H. Koopman

BEFORE you start to weld sheet steel the most important step is to clean the sheet edges. Then select a light-duty oxy-acetylene blowpipe with a head recommended by the manufacturer, for the thickness of metal you are going to weld. Sheet steel material up to $^1/_8$ in. in thickness usually requires no special edge preparation. On most jobs, complete penetration can be obtained by properly spacing the pieces of sheet to be welded. Detailed instructions for welding preparation are given in the article "Getting Ready to Weld," published in the July 1948 issue of THE WELDING JOURNAL.

Place the pieces of sheet steel you are going to weld on the welding table. Space them about $^1/_{16}$ in. apart at the right end of the seam and about $^1/_8$ in. apart at the left end as shown in Fig. 1. (This applies only to material up to $^1/_8$ in. in thickness.) These figures are for sheet 12 in. long and it is important to keep a space

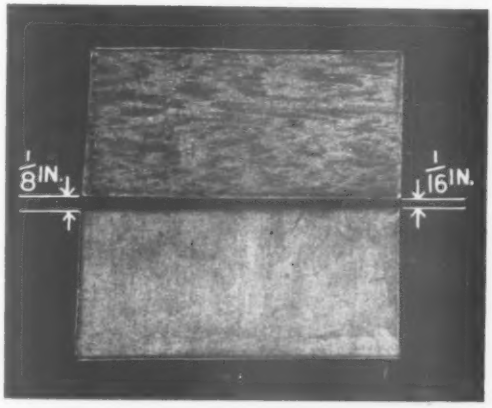


Fig. 1 Space the sheets about $^1/_{16}$ in. apart at the right end of the seam, and about $^1/_8$ in. apart at the left end. The space allows for the expansion of the metal during welding

K. H. Koopman is with The Linde Air Products Co., Newark, N. J.

* "Part II-Heliarc Welding" will follow at a later date.

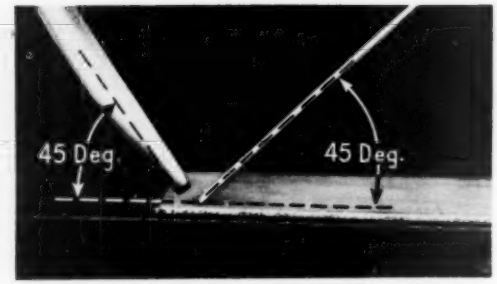


Fig. 2 This is the proper position for welding. Notice that the angle between the blowpipe and the surface, and the welding rod and the surface, is 45°

between the two pieces of sheet for two reasons. First, the spacing allows the metal to expand. If the spacing is too small the sheets will soon butt together and may even overlap. Of course, this would make it almost impossible to weld. Second, this small space allows you to melt the edges of the metal all the way to the bottom and obtain complete penetration.

Here's a general rule to remember when the material is more than 12 in. long. A space of $^1/_{16}$ in. should be maintained 12 in. ahead of the weld for the entire length of the seam. To keep this proper spacing you will probably need an H-type clamp that can be moved along as the welding progresses.

TACK WELDS

To keep the proper spacing between the two pieces of sheet metal, it is a good idea to tack weld the ends of the seams before welding. To make a tack weld, hold the lighted blowpipe and the rod as shown in Fig. 2. This is also the proper rod and blowpipe position for welding. Hold the blowpipe steady so that the flame will play upon the two corners at the right end of the seam. (These instructions are for right-handed welders.) Keep the edge of the welding rod in the outer part of the flame envelope. This will enable you to bring the rod to the proper temperature at the same time that the spot on the sheet is at the melting point.

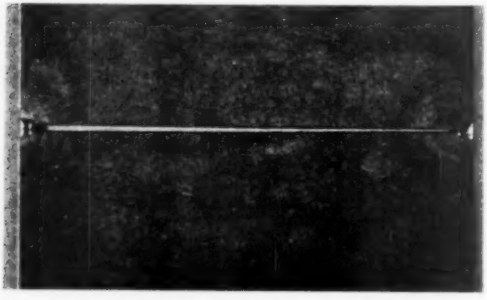


Fig. 3 Tack welds at each end of the seam keep the proper spacing between the sheets. To make a tack weld, heat the corners of both sheets. Allow the edges to break down slightly and flow together. Then add metal from the welding rod until you form a puddle about $^3/_{16}$ to $^1/_4$ in. in diameter

Just as two small spots of molten metal begin to form on these corners, add some molten metal from the welding rod. It will form a bridge between the two small puddles. Continue to play the flame upon this puddle, melting metal from the two corners and adding metal from the welding rod until the puddle has reached a diameter of about $^5/_{16}$ to $^3/_8$ in. Then allow the puddle to cool and solidify. Now, make certain that you can have the proper spacing between the two sheets and that they are flat and even. Then make a tack weld at the other end. When you have made the two tack welds, place the two sheets so that the narrow space is at the right edge of the sheets as shown in Fig. 3.

BUTT WELDS

You are now ready to start the weld itself. Place the sheet so that the seam will come over an opening in the

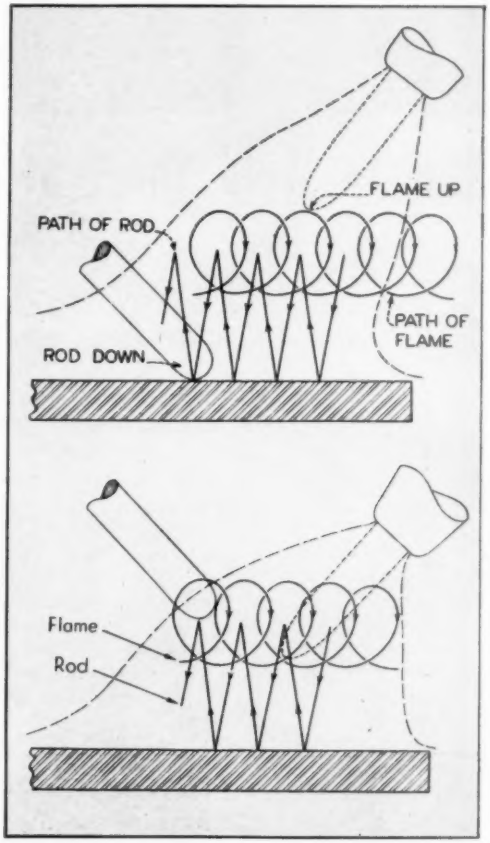


Fig. 4 The rod and blowpipe must be raised and lowered during welding. The top sketch shows the position of the rod and the tip when the rod is raised. Now the flame is heating the metal ahead of the weld. The lower sketch shows the position of the rod and tip when rod metal is added to the weld

table. If the table top is solid, place a piece of welding rod under the left end of the two sheets. If the sheet is flexible you may need more than one piece of rod. This provides an air space so that the weld and table do not touch.

Play the flame upon the tack weld at the right and remelt a small puddle on the surface. At the same time, hold the end of the rod within the outer envelope of the flame without actually melting it. When the tack weld starts to melt, add metal from the welding rod to increase the size of the puddle. As the puddle becomes larger and hotter, you will get the proper penetration. You must not let the puddle get too hot or the bottom will drop out and leave a hole. Build up the puddle a little above the top surface of the sheet. Keep the molten puddle $^1/_4$ in. in diameter, and move both the blowpipe and rod forward in a straight line across the sheet. The flame should move from side to side so that it is first on the edge of one sheet and then on the edge of the other. This will bring them both to the proper welding temperature at the same time.

KEEP THE ROD AND BLOWPIPE IN MOTION

While you are welding, the rod and the blowpipe must also be raised and lowered as shown in Fig. 4. Notice that when the rod is raised out of the way, the flame heats and melts the sheet ahead of the bead and forms a puddle. When the rod is lowered and placed in this puddle the flame melts the end of the rod, and the weld metal flows into the molten puddle. Do not allow molten metal from the rod to drop into the welding puddle, but lower the end of the rod into the puddle to add metal. If the rod sticks to the weld do not try to jerk it loose. Simply play the blowpipe flame directly on the end of the rod and it will quickly come free. Usually, the rod will stick only if it is cold and has not been heated in the flame or if the puddle is not in the proper condition.

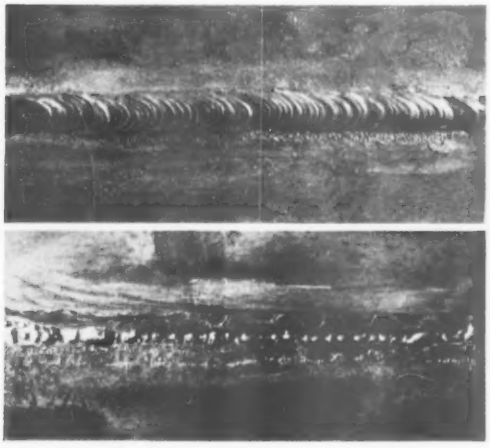


Fig. 5 The top picture shows the top surface of a good butt weld in sheet. Practice until your welds look like this. The underside of the same weld is shown in the lower picture. Notice that the weld penetrates completely through the sheets

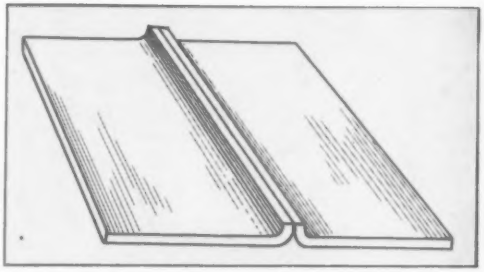


Fig. 6 To make a flange weld, turn up the base metal like this. No welding rod is added to a joint of this type. Clamp the pieces so that their edges touch

Two things should be watched closely. As you allow the molten metal from the welding rod to mix with the edges of the sheet steel, these edges should be molten and in puddle form. They should be in this condition all the way through to the underside of the sheet because this is the only way to get complete penetration.

The other thing to watch is the build up of the weld. It should be higher than the surface of the sheet. You can do this only by adding sufficient welding rod metal to the rear of the puddle.

Hold the blowpipe lightly so that you can guide it smoothly without jerks or without fatigue. If you are sitting down, hold the blowpipe like a pencil. Hold it like a fishing pole when you stand to weld.

FLANGE WELDS

The flange weld can be used frequently in sheet metal work. No welding rod needs to be added to make this weld. The metal required is furnished by the part of the base metal that has been turned up.

Place the two pieces of sheet on the welding table with the flanged edges just touching. Use clamps to prevent them from separating. The flanged strip can be made by hammering over the edge while the sheet is in a vice. It should be as wide as the sheet is thick.

Play the blowpipe flame on the right end until a small puddle begins to form. Increase the size of the puddle so that complete penetration is obtained. Then move the blowpipe along the seam slowly and steadily, always making sure that the puddle is hot enough to give good penetration. When the flanges melt you should obtain a built-up surface of the proper strength.

CORNER WELDS

When two pieces of sheet metal are joined at a corner you can use either of the three common designs shown in Fig. 7. To make a joint like the left-hand sketch, you must keep the two edges clamped together while

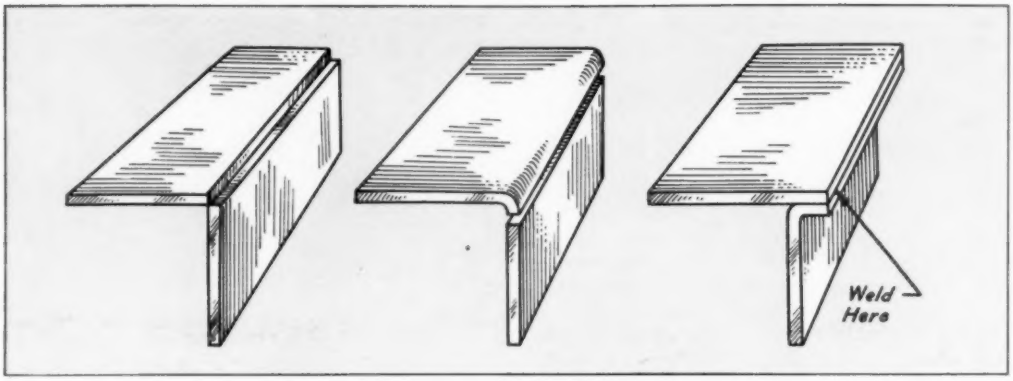


Fig. 7 Here are three common designs for corner welds. Welds in the left and center sketch are made like ordinary butt welds. The right-hand sketch is an ordinary flange joint

you make tack welds every 4 in. You do not need a tapered space. Then proceed to weld as you did when you made a butt weld. To make a joint like the one shown in the center sketch keep a small space, about $^1/_{32}$ or $^1/_{16}$ in., between the sheets. Then tack weld every 3 or 4 in. before making the final weld.

When you make flange welds like the one shown in the right-hand sketch, the edges are held together by clamps. Visible penetration is not made. Pass the blowpipe steadily along the edges and allow the metal to melt. It will flow together and form a sort of bridge of molten metal across the two edges.

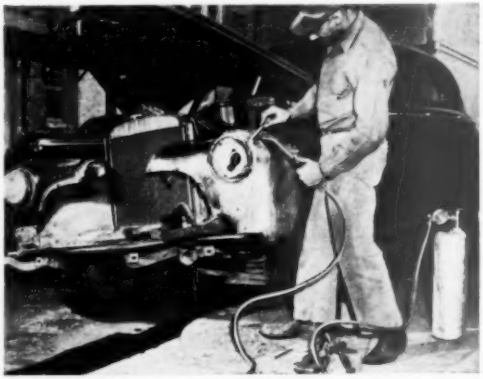
Ironing Out Crumpled Fenders

Air acetylene torch helps you make smooth fender repairs

by F. C. Geibig

NO MATTER how much hammering and ironing you do on a crumpled fender there are always some marks and crevices that will not come out. One way to get a smooth fender that looks like new is to apply solder to the damaged spots. After you have hammered out all the wrinkles possible, use a wire brush, sandpaper and steel wool on the fender. Then paint the fender with muriatic acid. Be careful with the acid and keep it off your clothing and skin. Heat the fender with an air-acetylene torch until the acid dries. Put on another coat of acid and heat a second time until the acid dries. The secret of a top-notch job is the thoroughness with which you clean the area. The two coats of acid provides a good fluxing action and makes it easy to flow the solder onto the fender.

After the second heating, apply ordinary stick solder to the damaged part of the fender. Use just enough heat to reduce the solder to a pasty condition. Too much heat will cause the solder to run and in this con-



Apply two coats of muriatic acid to the fender. Heat the fender after each coat with a torch, until the acid dries. Then apply stick solder after the second coat of acid

F. C. Geibig is with The Linde Air Products Co., Newark, N. J.

After you hammer out the dents and creases, clean the fender with a wire brush, sandpaper and steel wool. Remember, that to get a good job you must have a perfectly clean surface

Use a wooden paddle to work the solder into crevices that still remain in the fender. Be sure to keep the solder pasty. Too much heat will make the solder run, and you will have trouble controlling it

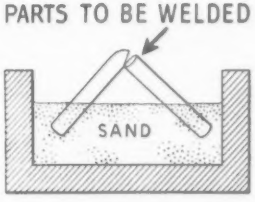
dition it is difficult to control. After you have applied some solder, use a small wooden paddle to smooth the solder over the fender. Work it into any marks or crevices that are still in the fender. Continue to apply solder until the fender is even and smooth and there are no dents or marks. When the solder cools, the fender is ready for the finishing operation of sanding, priming and painting.

For this job the operator used a No. 5 stem because the repair was made in front of the shop on a windy day. For inside work he would use a stem one or two sizes smaller. The air-acetylene torch is useful for most soldering, heating or bending jobs in the shop. It is valuable for automobile repair shops, plumbing shops, installers or repairers of refrigeration or air-conditioning systems and any other shops that work with metal.

Two Useful Ideas

by Duane R. Maxwell

THE first one is to take a good-sized wooden box or an old boiler and fill it full with a coarse sand or gravel. When you have an unusually hard or funny shaped job to weld and can't seem to line it up properly by bracing it just line it up in a box of sand as illustrated.



And where most shops use lime to cool a welded casting or cure it slowly we have found that Eagle "66" boiler plaster in its dry form holds the heat and allows the welded casting to cool off much slower than the lime. We have had exceptionally good luck with gears and wheels with long narrow spokes and high stress points.

Data and illustration supplied by Air Reduction Sales Co.

Getting Ready to Bronze Weld

by K. H. Koopman

CLEAN the part thoroughly—that is the secret of all good bronze welds. Here is why. You get a strong bronze weld only when the molten bronze rod flows easily and evenly over the metal surface. It is called "tinning." It acts just like water on clean glass. When water is spread on a glass plate that is not clean, it will separate into tiny drops. Molten bronze rod does the same thing on dirty steel or cast iron, and when it does not flow evenly the weld will be weak.

Remove all oil, grease, scale, rust or oxides from the beveled edges or the facing edges of the part. The top and bottom surfaces should also be cleaned for about a half inch back from the edges. This mechanical cleaning should be done by a grinder, stiff wire brush, file, emery cloth or steel wool. If the cleaning is done by grinding, go over the part afterward with a file to remove any small particles picked up from the grinder.

The surface of the edges to be welded must also be cleaned chemically. That means that you must use a liberal amount of flux when you weld. The flux can be sprinkled in the weld area or applied by dipping the end of the heated rod into the flux can. Welding rods that have been precoated with flux are also available. With these rods you are always sure of getting the proper amount of flux in the weld and you save time that would be spent in dipping the rod into the can.

JOINT PREPARATION

When the material is more than 1/8 in. thick the edges of each part should be beveled to a 30 to 45° angle. Just as in fusion welding, you must get complete penetration through the bottom of the vee. Beveling the edges of heavy sections as shown in Fig. 3 will help you to get the proper penetration. For thinner material just clean the edges. The edges of all material, including cast iron, steel, copper, brass and galvanized iron should be prepared in the same way.

Grinding, chipping and machining are suitable methods for beveling these edges. However, these methods may smear the graphite present in a gray iron casting and make proper tinning difficult. The graphite can be removed by heating the edges to a dull red with a blowpipe using a slightly oxidizing flame, then cleaning them with a wire brush when they cool.

K. H. Koopman is Development Engineer, The Linde Air Products Co., Newark, N. J.

Fig. 1 Here is the broken casting before it was cleaned or beveled

Fig. 2 The break has been beveled to about a 90° angle, and the surface has been cleaned for about 1/2 in. back from the edge. Notice, too, that the vee does not go across the break. This helps to line up the parts

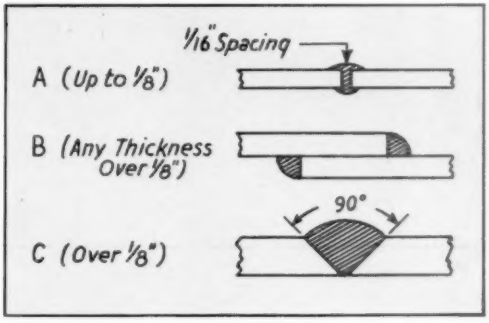


Fig. 3 This sketch shows two types of joints for metal up to 1/8 in. thick and more than 1/8 in. thick

A Special Treat for Plowshares

by W. B. Sharav

WHAT is different about the plowshare in Fig. 1? It looks like an ordinary plowshare, but it will last more than twice as long. That's because it has been flame hardened. Flame hardening consists of quickly heating steel to a bright red, and then cooling it with a water quench. This increases the hardness of the steel. You can flame harden and extend the life of used plowshares or old ones that have been rebuilt with steel.

W. B. Sharav, Development Engineer, The Linde Air Products Co., Newark, N. J.

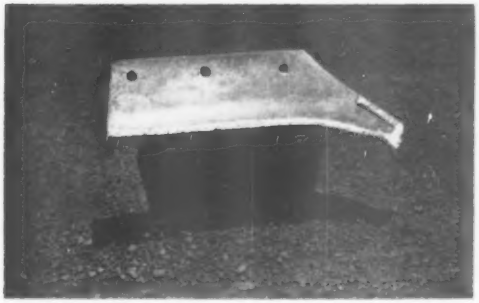


Fig. 1 This plowshare was rebuilt and then flame hardened. It will last more than twice as long as untreated shares

On this job, the plowshare was heated with the oxy-acetylene blowpipe. A medium-sized tip was used and the flame was adjusted to neutral. The plowshare was heated to a cherry red and followed with a water quench as shown in Fig. 2. Care must be taken to heat the share for a distance of only half an inch from the edge. If you heat beyond this point, you may cause cracks in the plowshare. It is necessary to heat the share only on one side. Notice that the quench is provided by an ordinary water hose. A section of an I-beam is used as a support for the plowshare and as a run-off trough for the water.

Fig. 2 The share is heated to a cherry red followed by a water quench. The heated zone must not be carried back more than $\frac{1}{2}$ in. from the edge

Cutting Makes the Job Easy

by E. M. Holub

HOW many times have you left some of your skin—from your knuckles and arms—under a battered fender while you have tried to remove the bolts? Fenders and body sections come off easily in the shop that cuts them off with their cutting blowpipe. When a fender must be replaced, one shop gets out the cutting blowpipe and cuts off the fender almost before they could find the right size wrench.

E. M. Holub is Development Engineer, The Linde Air Products Co., Newark, N. J.

The cut is made about $\frac{1}{2}$ in. from the body, as shown in Fig. 2, leaving a narrow flange. To keep from burning the paint on the body, it's a good idea to protect it with a paste made from asbestos cement and water. After the fender is cut off, it's an easy matter to remove the body bolts, without skinning your fingers. When the bolts are badly rusted, heat them to a dull red. Let

Fig. 1 Here the operator is cutting out a rusted body strip quickly and easily. Notice that the cut is clean and smooth

them cool and they'll come off easily with your wrench. Four fenders can be removed by this quick method in the same time another body man can remove the body bolts with a wrench and take off one fender.

This same shop has a quick method for straightening body sections, too. They cut out the damaged section from the door or other part of the body with their cutting blowpipe. Then they take it to the bench, straighten and form it and weld it back in place. All this takes just a few minutes time. When the weld is ground, smoothed over with body solder and painted, the door looks like new. Be sure that any flammable part is protected when you weld or cut on body parts.

Fig. 2 When you replace fenders, cut them off ½ in. from the body with your cutting blowpipe. Then it is an easy matter to remove the body bolts

Fig. 3 The dents in this body section have been removed and the operator is now welding it back in place. It will look like new when it is painted

the AMERICAN WELDING SOCIETY

activities • related events

M. M. Kelly to Become Secretary Emeritus

After thirty years of continuous and arduous service with the AMERICAN WELDING SOCIETY, Miss Kelly's request for a less responsible role than Secretary was granted by the Board of Directors on May 13th and a special by-law change was approved to permit the SOCIETY to retain her wealth of experience in a consulting capacity under the title of Secretary Emeritus.

Actually, Miss Kelly will retain her present title until October 1st, the Board having granted her a four-month leave of absence. Under her able guidance the SOCIETY budget grew from $18,500 in 1923 (the first official budget) to over $288,000 for the current year. Membership likewise grew from 217 members in 1919 to a high of over 8000 during the last World War.

For those who like a biography, the following facts are pertinent. She received her business training at Columbia University. Her first assignment was serving as a member of a group from Columbia University appointed to assist the Italian Aviation Commission that came to the United States during the first World War, under the direction of Major Perfetti for the purpose of inspecting American methods and equipment.

During 1918 she was appointed secretary to Dr. C. A. Adams, then Chairman of the Welding Committee, Emergency Fleet Corp., U.S.S. Shipping Board. Dr. Adams was, at that time, also President of the American Institute of Electrical Engineers.

From 1919, when the SOCIETY was organized, to date, she has been a member of the A.W.S. staff, in positions of Assistant Secretary from 1919 to 1920; Acting Secretary from 1920 to 1922; and Secretary from 1922 to date. In 1937, the title of Assistant Treasurer was added. During that period, she served directly some 23 presidents of the SOCIETY, and six national treasurers; up to a few years ago, she assisted in the organization of Sections; developed and improved with experience, procedures for Section operation. Miss Kelly has been Secretary of a number of the Standing Committees, and for the past 25 years, has been Secretary of the Convention Committee.

Her friends, and they are many, join in wishing her many more years of health and happiness in the new role she has chosen.

Nomination of Officers and Directors American Welding Society

At its meeting on April 25, 1949, the Nominating Committee of the AMERICAN WELDING SOCIETY unanimously selected the following officers and directors for the year 1949–50.

President, O. B. J. Fraser, The International Nickel Co., New York, N. Y.

First Vice-President, H. W. Pierce, New York Shipbuilding Corp., Camden, N. J.

Second Vice-President, R. E. McFarland, Western Electric Co., Chicago, Ill.

Board of Directors (for three years): L. C. Bibber, Carnegie-Illinois Steel Corp., Pittsburgh, Pa.; A. F. Davis, The Lincoln Electric Co., Cleveland, Ohio; A. J. Moses, Combustion Engineering-Superheater, Inc., Chattanooga, Tenn.; Gilbert S. Schaller, University of Washington, Seattle, Wash.

Nominations for the District Vice-Presidents are:

District 1, H. S. Swan, American Locomotive Co., Schenectady, N. Y.

District 3, L. C. Stiles, Chicago Bridge & Iron Co., Birmingham, Ala.

District 5, John Grodrian, Bendix Products Div., Bendix Aviation, South Bend, Ind.

District 7, W. F. Boyle, The Pelton Water Wheel Co., San Francisco, Calif.

Welding Metallurgy —Iron and Steel— Second Edition

If there is one subject which is of interest to everyone who is welding minded it is welding metallurgy. This explains the large attendance at the educational lectures (on welding metallurgy) at the A.W.S. Annual Meeting last fall; the preference for this subject as a topic for Local Section educational lecture series; and the record sales of the first edition of *Welding Metallurgy* by Prof. O. H. Henry and Dr. G. E. Claussen.

After several printings of the first edition it was decided that a revised edition incorporating new information and bringing the old information up to date was advisable.

After three years of work, this new Second Edition by G. E. Linnert of Armco Steel Corp. is now ready. It is new and larger, contains more information, has an improved arrangement and presentation, and is even more handsome.

The new information—150 more pages and a total of 203 illustrations—covers new processes such as inert-gas metal-arc welding and includes more information on some of the materials such as the stainless, heat-resisting and stainless-clad steels.

Deliberate effort has been made to keep the language simple; where technical metallurgical terms have been used they have been defined.

The basic theory of metallurgy is described in the first few chapters of the book for those having no previous knowledge of the subject; later chapters cover the welding metallurgy of different materials and the effect of different elements on welding. These chapters should be of interest to all readers.

The arrangement has been changed making the book easier to read and handier to use. An extensive index has been added for ready reference. A list of suggested reading has been included at the end of each chapter containing suggested sources for more detailed information on the subject covered by that chapter. The usefulness of the book as a school text or individual home study has been increased by grouping a series of questions on each chapter, at the end of the book.

Much thought has been given to appearance. A better paper has been used, the illustrations have been redrawn to make them uniform, and the material has been arranged so that there is a pleasing balance between text and illustrations.

All of this improves the readability as well. Finally, the book is bound in a heavy, blue cloth cover with title and A.W.S. emblem stamped in gold.

Neither effort nor expense have been spared to bring this book to you as a useful contribution of your SOCIETY of which you can properly be proud.

Members of A.W.S. are entitled to one copy of *Welding Metallurgy* at the special price of $2.00 by using the coupon which has been sent to them. The price for nonmembers is $2.50. Send your order to the AMERICAN WELDING SOCIETY, 33 West 39th Street, New York 18, N. Y.

Standard Welding Terms and Their Definitions

Welding has its own Noah Websters, and its a good thing too!

Did you ever have the experience of talking to someone about welding and discover after 20 or 30 minutes that you were each talking about two different things; or maybe you have spent a long time arguing with someone only to discover that you were in full agreement—except that you did not speak the same language! This sort of thing can be quite costly especially where correspondences between distance points on large project is involved.

To provide a basis of understanding with regard to welding, the A.W.S. Committee on Definitions has spent more than four years of intensive work in getting up the *Standard Welding Terms and Their Definitions*, which now replaces the publication issued in 1942 titled "Definitions of Welding Terms and Master Chart of Welding Processes." In the course of its work, the Committee consulted with industry, reviewed the literature and carefully studied the technical and scientific aspects of welding in order to formulate a terminology which would be technically sound yet in close conformance to common usage. To establish a correct terminology it was also necessary to clarify many basic concepts such as "What is fusion?" "What is bond?" "What is penetration?" and to properly distinguish between related terms such as "back weld" and "backing weld," etc.

The new *Standard Welding Terms* furnishes more than 500 welding terms and their definitions and includes 57 related illustrations. The terms are listed dictionary-wise or alphabetically and also grouped according to process in a separate listing at the end of the booklet.

When work was first started on this new terminology the need for making basic terms applicable to different processes became evident. To keep its thinking straight the Definitions Committee prepared a revised Master Chart of Welding Processes listing all 37 welding processes in commerical use today and a series of Process Charts showing the similarities and differences between related processes. With the thought that these charts would similarly assist the users of the *Standard Welding Terms* it has been decided to publish them concurrently with the *Standard Welding Terms*. There are five Charts in all, ranging in size from 8½ by 11 in. to 11 by 50 in., fastened together and enclosed in an envelope for convenience in filing. The charts may easily be detached for mounting on shop, office or schoolroom walls.

Copies of these publications may be obtained from A.W.S. Headquarters, 33 W. 39th St., New York 18, N. Y., at $1.00 per copy for the *Standard Welding Terms and Their Definitions* and 35 cents per copy for the Master Chart of Welding Processes and Process Charts or $1.25 if purchased together. The usual discounts to members will apply.

$2250 in Prizes for Papers on Resistance Welding—Contest Closes July 31, 1949

Prizes and Contest Rules

Announcement has been made of cash prizes to be awarded in 1949 by the Resistance Welder Manufacturers' Assn. for outstanding papers dealing with resistance welding subjects. The total amount of the awards is $2250, and a wide choice in subject matter is allowed in order to assure eligibility to all papers which cover worthwhile and significant achievements in the field. The contest judges will be appointed by the AMERICAN WELDING SOCIETY, and awards will be made at the

Built by Jakobson Shipyard, Inc., Oyster Bay, L. I., this new Diesel-electric tug typifies the progressive policy of Erie which is equally as advanced in the marine as the rail division.

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Welding Electrodes
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11,500 lbs. of Blue Devil (E 6010); 6000 lbs. of Gray Devil (E 6012) and 2000 lbs. of Graydac (E 6013) *CHAMPION WELDING ELECTRODES* were used in construction of the new Erie R.R. steel tug Paterson recently entered in service in New York Harbor.

The merit of *CHAMPION WELDING ELECTRODES* is emphasized by the fact they were selected for this severe application where industrial waste and salt water in the area cause a high incidence of corrosion.

Be sure you have a copy of our new booklet *"How to Choose and Use the Correct Electrode."* Available on request.

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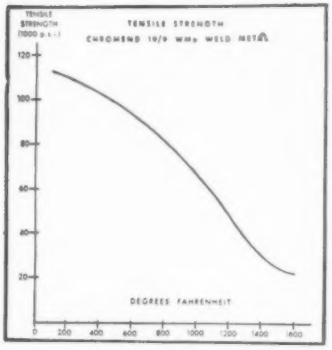
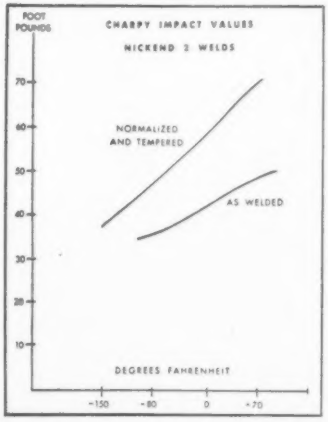
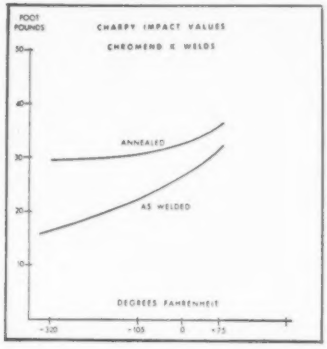




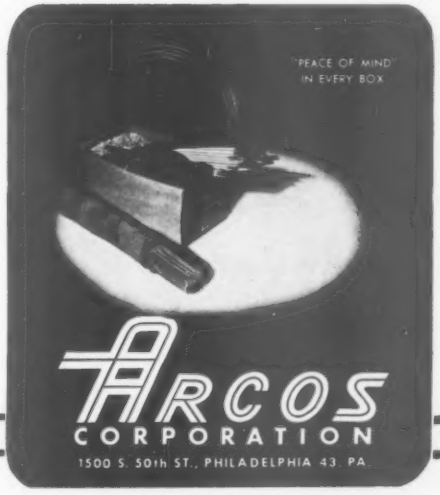


MANY YEARS AGO Arcos was asked to develop electrodes to give weld metal to withstand temperatures in the 1800°- 2000° F range. Arcos did it.

Recently Arcos was asked to develop electrodes to give weld metal to meet service requirements at temperatures in the sub-zero range. Arcos did it.

These achievements reflect the ability and competence which produces electrodes to give the very highest quality weld metal for any kind of service conditions.

Consistently good welds are obtained when Arcos electrodes supply the weld metal.



ELECTRODES • COILED WIRE • BARE ROD

1949 Fall Meeting of the SOCIETY. The prizes and rules governing the contest are as follows:

One prize of $750 for the best paper emanating from an industrial source, consulting engineer, private or government laboratory, or the like, the subject matter of which is concerned specifically with resistance welding. There are no restrictions on the scope of the subject matter. For example, it may be devoted to redesign of a product or products for resistance welding, improvement (from a welding and cost viewpoint) in a present design for resistance welding, resistance welding research, development of new procedures to broaden the field of application of resistance welding, etc. Papers in these categories should explain the economic importance of the accomplishments described—that is, cost savings, production improvement, scope of application, etc.

A prize of $500 for the second best paper in the above classification. A prize of $250 for the third best paper in the above classification.

A prize of $300 for the paper emanating from a University source (the author of which is either an instructor, graduate student or research fellow) which in the opinion of the Board of Award is the greatest original contribution to the advancement and use of resistance welding from this source.

A prize of $200 for the second best paper in the above classification.

A prize of $250 for the paper emanating from a University source (the author of which is an undergraduate student) which in the opinion of the Board of Award is the greatest original contribution to the advancement of resistance welding from this source.

The contest is open to anyone, without restriction, from the United States, its possessions and Canada. It is also open to any member of the AMERICAN WELDING SOCIETY in any grade from any place in the world. The contest is considered as having opened Aug. 1, 1948. In order to be eligible for this contest all papers must be forwarded so as to be delivered at AMERICAN WELDING SOCIETY headquarters no later than 5:00 P.M., July 31, 1949. Papers which are to be presented at the Annual Meeting of the AMERICAN WELDING SOCIETY in October may also be entered in this contest, in which case a draft or copy of the paper must be filed with the AMERICAN WELDING SOCIETY not later than July 31, 1949. To be eligible, author must indicate paper has not been considered previously in the contest, or shall not have been presented or published elsewhere prior to its appearance in THE WELDING JOURNAL.

All papers submitted in the contest become the joint property of the R.W.M.A. and the AMERICAN WELDING SOCIETY, who will retain all rights thereto. The AMERICAN WELDING SOCIETY will appoint five judges, who will judge the relative merits of the various papers submitted and make the awards accordingly. The decision of the judges will be final.

For the author or authors to be eligible for this award, the paper shall describe clearly original work done by them or under their supervision on resistance welding in any of its aspects by any method or process. The paper shall be a full disclosure of the subject. The paper shall contain no statement which is unethical advertising or sales promotion. The paper may contain statements of fact, including the names of either individuals or organizations of any kind, commercial designations, trade names, etc. The minimum length requirement is 2500 words.

All papers must be typewritten, double spacing, written on one side only of blank white paper. Photographs, charts, graphs, etc., may either be attached directly to the copy or may be detached, in which case they should be clearly identified with figure numbers, captions, etc.

Papers entered in this contest should be sent to AMERICAN WELDING SOCIETY, 33 W. 39th St., New York, 18, N. Y. If mailed to arrive not later than July 1, 1949, three copies should be furnished. If mailed to arrive between July 1 and July 31, 1949, six copies should be furnished.

Western Metal Congress

Success of the Western Metal Congress and Exposition, five-day event which ended April 15 in Los Angeles, prompted William H. Eisenman, secretary, American Society for Metals, to announce the technical sessions and show hereafter will be held every two years on the Pacific Coast.

The 1951 meeting place, he said, may be Oakland or San Francisco. Four years hence, it undoubtedly will be Los Angeles.

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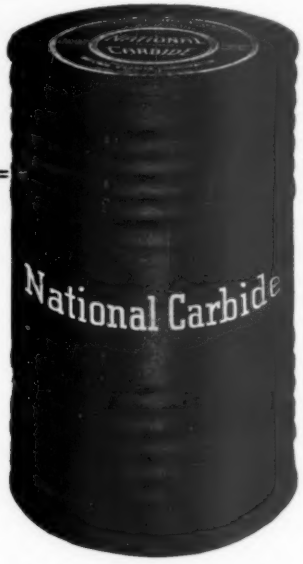

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event was approximately 25,000. In addition, audiences totaling about 15,000 sat at the technical sessions. Comment on the papers presented was that their standards rated higher than those at any previous Western Metal Congress.

The large attendance figures, Eisenman said, attest to the industrial expansion of the West. Plants in 11 western states were represented by metal engineers, purchasing agents and other management.

Exhibitors commented on the "quality" of the crowd which attended the exposition. No effort was made to attract the general public. The exposition was conspicuously devoid of movie stars, jazz bands and other artificial stimulators and distractions.

Its one purpose was to present valuable technical information to audiences which knew what to do with it when they got it. As a result the congress and exposition were decided benefits for the industry of the western area.

Speakers on technical programs, including participants in round-table discussions numbered 96. Exhibits totaled 211.

Exhibitors were enthusiastic over sales contacts made, and the general interest manifested by spectators.

Booths were manned by technical engineers, who undertook to explain products and solve problems of those who visited their displays.

Many who attended both the technical sessions and the exhibitions said they accumulated as much information from one phase of the double event as from the other. This, in itself, was a tribute to the men in the booths who for five solid days put best feet foremost at helping others in untangling knotty plant perplexities.

Seventeen technical societies, most of them national in scope, cooperated with the A.S.M. in presenting the congress and exposition. Those which held their own technical meetings, in addition to A.S.M. were AMERICAN WELDING SOCIETY, American Foundrymen's Society, American Institute of Mining and Metallurgical Engineers and the Society for Non-Destructive Testing.

Eisenman plans to invite the same technical groups to take part in the next Western Metal Congress. In addition to those presenting programs, the following cooperated in a wide variety of ways: American Chemical Society, American Institute of Electrical Engineers, American Petroleum Institute, American Society of Civil Engineers, American Society of Mechanical Engineers, American Society for Testing Materials, American Society of Tool Engineers, National Association of Purchasing Agents, Pacific Coast Electrical Association, Pacific Coast Gas Association, Purchasing Agents Association of Los Angeles, Society of Automotive Engineers and Western Oil and Gas Association.

Annual Meeting American Society for Testing Materials

In addition to 22 officially numbered technical sessions scheduled for the 52nd (1949) Annual Meeting of The American Society for Testing Materials, Atlantic City, during the week of June 27th, there are a number of other informal sessions and round-table discussions which will be of much interest. There will be symposiums and groups of technical papers, and reports of interest to those concerned with ferrous and nonferrous metals: cementitious, concrete and related fields; rapid identification of metals; bituminous materials; and many others.

Throughout the entire 5 days of the meeting scores of the A.S.T.M. technical committees will be in session perfecting and completing work on specifications and tests that has been under way, and initiating new research and standardization work. In addition to the extensive business to be transacted, there is to be a social period on Wednesday evening, June 29th, when the hosts for this meeting, the Philadelphia District, are sponsoring an informal program of entertainment. All sessions are at Chalfonte-Haddon Hall.

Another interesting innovation in the program is the official luncheon session scheduled for Tuesday noon, June 28th, when President R. L. Templin will give the annual President's Address, 50-year members will be recognized and other honors awarded.

The 1949 Edgar Marburg Lecture, which commemorates the name of the Society's first Secretary, will be on the subject, "Residual Stresses in Metals" by Dr. William Marsh Baldwin, Jr. Dr. Baldwin is Research Professor and Director of the Metals Research Laboratory of the Department of Metallurgical Engineering at Case Institute of Technology.

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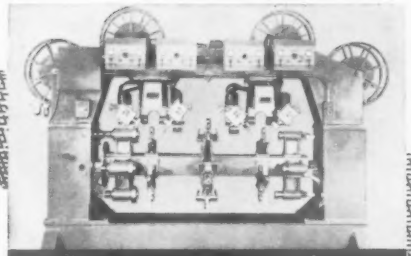
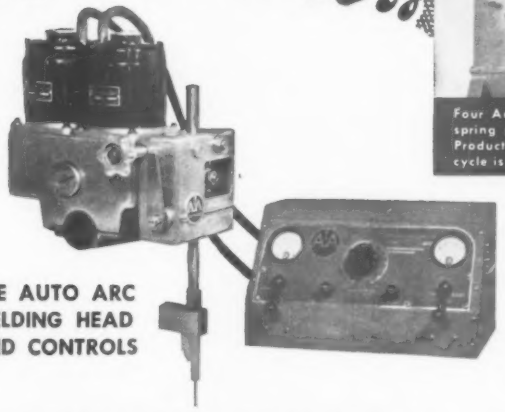
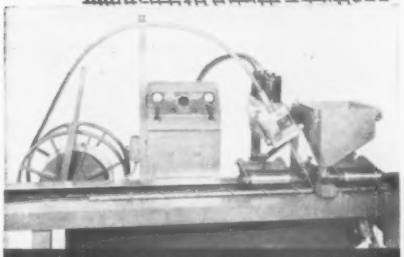


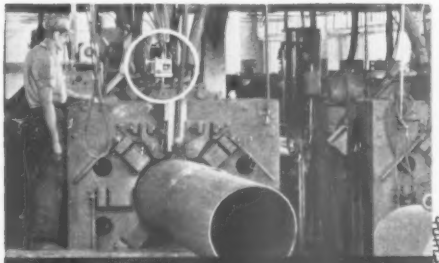
Four Auto Arc Welding Heads automatically weld spring pads on passenger car rear axle housing. Production rate is four housings per minute; welding cycle is 11 seconds per housing.



THE AUTO ARC WELDING HEAD AND CONTROLS



An Auto Arc Welding Machine for fabricating augers. The auger moves under the arc for welding the flight to the tube. The machine may be set for continuous welding.



Auto Arc Welding Heads are utilized in the continuous production of large diameter, high pressure pipe. Both A. C. and D. C. welding are used, with each arc supplied from a 1500-ampere capacity unit

is the word for AUTO ARC

The versatility of the standard Auto Arc Welding Head is illustrated by the range of applications. The production of 16 open-arc welds per minute with four heads requires good arc starting features. Another installation with two heads starting simultaneously with 380 amps. A. C., submerged-arc on 5/32" electrode, has a welding cycle of 30 seconds.

Continuous welding is maintained in a pipe mill where uniform arc control is necessary to secure desired penetration. After welding, the pipe is expanded hydraulically with pressures of 1500-2000 lbs. p.s.i.

Auto Arc equipment is also successfully operating on steel mill applications of hard surfacing materials in high temperature zones.

Where automatic arc welding is applicable to your production, let our engineers estimate its economy.

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Yes, if you are looking for higher quality, increased production and lower costs with your aluminum alloy spot welding operation, investigate the Diversey Pre-Welding Treatment today!

Used by leading aircraft companies, case histories reveal that, by employing Diversey No. 36 to remove identification markings, grease, dirt; and by using Diversey No. 514 to remove oxide and heat scale, spot weld output increased up to 50%! Further, plants report an increase up to 4,000% in the number of spot welds now made before the electrode tips require redressing!

The Diversey Pre-Welding Treatment for Aluminum is easy, efficient, practical, and surprisingly economical to use! Mail the handy coupon today for complete information!

EASY AS A-B-C!

The cleaning efficiency of Diversey No. 36 is dramatically shown here! Before and after photos prove that Diversey No. 36 removes marking inks from aluminum surfaces easy as A-B-C!

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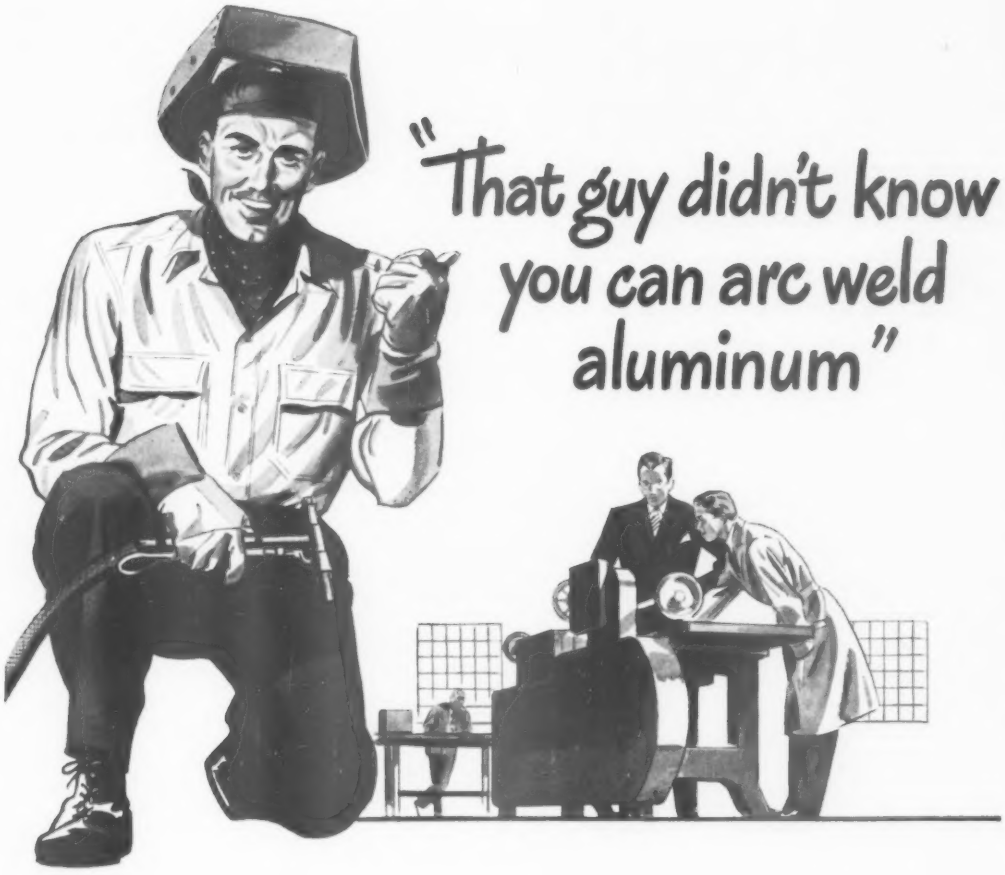


"That guy didn't know you can arc weld aluminum"

You tell him. Show him the spatter-free, oxide-free seam that you've just finished on the Alcoa Aluminum pipe joint. Let him take a look at your argon-shielded, tungsten arc torch. Tell him you've been welding aluminum for the past 20 years.

Take him over to that outfit next door that makes aluminum storm windows. Show him the battery of resistance welders that knocks out 100 Alcoa Aluminum frames an hour.

Tell him about your buddy, who works over at the railroad car shops. Give him the word about those liquid-proof, pressure-proof Alcoa Aluminum tank cars he arc welds.

As a matter of fact, we could do a bit of showing ourselves. We take our own medicine, barrels of it. Over in the Alcoa plant at New Kensington, Pennsylvania, some days we weld over 1500 Alcoa Aluminum beer barrels.

We've written a book called "Welding and Brazing Alcoa Aluminum". It's packed full of technical data and how-to-do-it welding procedure for all the welding processes. Your skeptical friend can have a free copy. His nearby Alcoa Sales Office will give him one, or he can write ALUMINUM COMPANY OF AMERICA, 1933 Gulf Bldg., Pittsburgh 19, Pa.

ALCOA FIRST IN ALUMINUM

PERSONNEL

Resistance Welding Institute

Establishment of The Resistance Welding Institute, an educational organization for the dissemination of information on technical advances in resistance welding, was announced recently. Simultaneously, announcement was made of the appointment of Lee H. Judge, industrial public relations executive, as Director of the Institute, with headquarters in Cleveland, Ohio.

Sponsored by a number of companies interested in resistance welding, the Institute has been created to make available to industry up-to-the-minute facts on spot, seam, flash and projection welding.

The pyramiding industrial demand for more information about designing products for resistance welding is cited as the principal requirement for establishing the Institute. Adoption of resistance welding for the fabrication of all kinds of metal products has grown at such a rate since the war that deliveries of resistance welding equipment to industry currently are more than five times the annual shipments during the 1938–39 prewar period.

World War II was to a large extent responsible for the tremendous growth of resistance welding. During the war, industry was faced with the necessity for turning out vast quantities of fabricated metal assemblies of all kinds at unprecedented output rates.

Resistance welding was found to be a major answer and this in turn served to point the way for industry toward greater utilization of resistance welding processes for peacetime products.

Lee Judge, Director of The Resistance Welding Institute, brings to the organization a broad background in industrial public relations and education. Formerly on the creative staff of The Earle Ferris Co., New York public relations counsel, he was more recently associated for several years with a Cleveland advertising agency serving such accounts as The Lincoln Electric Co., The Thew Shovel Co., The Erie Railroad and several trade associations.

A graduate of Cornell University, he was a Captain in the Corps of Engineers, first as a combat company commander overseas and later as Public Relations Director for Fort Belvoir and The Engineer Board.

Lee Harrington Judge, Newly Appointed Director of the Resistance Welding Institute

A. J. Fausek New President of International Acetylene Association

Arthur J. Fausek, president of Modern Engineering Co., St. Louis, Missouri, was elected president of the International Acetylene Association at the annual business meeting held during this organization's recent Annual Convention in Pittsburgh, Pa. Mr. Fausek had served as vice-president for the year 1948.

C. E. Monlux, vice-president, The Linde Air Products Co., was elected vice-president of the Association. E. V. David, assistant manager of the Technical Sales Division, Air Reduction Sales Co., New York was re-elected treasurer. H. F. Reinhard was re-elected secretary.

Arthur J. Fausek was born in St. Louis, Missouri. He is an alumnus of University of Missouri. In 1911 he and his brother, Irving F. Fausek, organized the Modern Engineering Co., to produce oxy-acetylene welding and cutting torches and other equipment.

Mr. Fausek has devoted the major portion of his lifetime to the interests of the oxy-acetylene industry and has been active in associations such as the Gas Products Association, the International Acetylene Association, the Compressed Gas Association, and the Independent Oxygen Manufacturers' Association.

Ihrig Honored

Dr. Harry K. Ihrig, Vice-President and Director of Laboratories of Globe Steel Tubes Co., Milwaukee, Wis., received a citation for distinguished service in engineering from the College of Engineering of the University of Wisconsin at Madison on March 15th. Dr. Ihrig is a member of the AMERICAN WELDING SOCIETY.

Kaufman Made Sales Manager

The appointment of Fred A. Kaufman as Sales Manager of the Electrode Division was recently announced by The McKay Co.

Mr. Kaufman was formerly Chief Metallurgical Engineer in charge of Technical Service, Research and Quality Control at McKay's Electrode plant in York, Pa. Before becoming associated with The McKay Co. in 1947, he did research in arc welding on the McKay fellowship at the Mellon Institute of Industrial Research, was Metallurgical Engineer with the Carnegie Illinois Steel Corp. and Plant Metallurgical Engineer with the Crown Can Co. in Philadelphia.

A graduate of Grove City College, he did graduate work at Carnegie Institute of Technology and the University of Pittsburgh.

Mr. Kaufman is a member of the American Institute of Mining and Metallurgical Engineers, the AMERICAN WELDING SOCIETY and the American Society for Metals and American Ceramic Society.

F. C. Neal Appointed Manager, Distributor Sales

Frank C. Neal, Jr., has been appointed Manager of the Distributor Sales Division of General Electric's Welding Divisions, C. I. MacGuffie, Manager of Sales, Welding Divisions, has announced. Effective March 15th, Neal assumed responsibility for the distribution and marketing of the Welding Divisions' products through distributors. He will make his headquarters at Fitchburg, Mass.

Frank C. Neal, Jr.

A graduate of Kansas University in 1936, Neal immediately became associated with General Electric in the test department at Schenectady. In 1938 he was assigned to the International General Electric Co. He joined the G-E welding section the following year, handling application engineering and problems relating to welding. In this capacity he made extensive studies of factory welding production, including automatic applications as well as both a.-c. and d.-c. welding. He was appointed district arc-welding representative for the Dallas, Tex., area in 1941, and in 1946 was transferred to Houston, Tex., to set up a welding division sales and service office.

Neal will be succeeded as manager of the G-E Houston Welding Division by Preston D. Morgan.

Boosts Welding Speeds 75% with "Manual Lincolnweld"

By EDW. F. ARNTZEN
Sales Engineer
A. C. Woods & Co., Rockford, Ill.

USE of the hidden arc welding process of the "Manual Lincolnweld" in the fabrication of machine tool weldments has increased our welding speeds three to six times over previous hand welding . . . has eliminated spatter cleaning, minimized joint preparation, and reduced distortion and cracking problems. These cost savings and product improvements contribute materially to the advantages already gained by the changeover of these parts to welded design.

In fabricating the weldment shown in Fig.1, we assemble and hold in place the various members by tack welding. The units are then sent to the welding floor for complete welding. Finish welds are made with the "Manual Lincolnweld" machine except at inaccessible places where hand welding is used. On parts such as this, we have increased welding speed 50% to 75% with "Manual Lincolnweld." All welds were made with a single pass, and very little distortion and no cracks were encountered.

To weld channels into box sections for press frames, we clamp the welding gun to a radiograph as shown in Fig. 2. Joints are ⅜" thick, bevelled. The 45-inch single butt welds (one on each side of the box) are made at a speed of 25 inches per minute. Floor-to-floor time is 10 minutes, compared to 30 minutes for the former method.

The high speed of "Manual Lincolnwelding" reduces distortion and joint-cracking problems which were formerly encountered in large parts such as the base shown in Fig. 3.

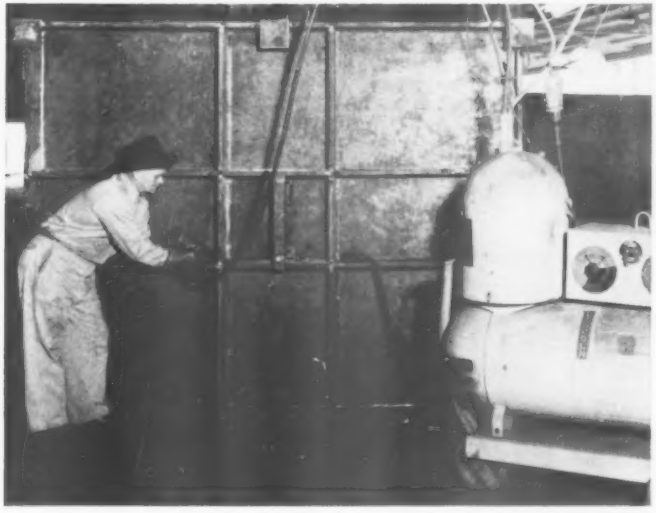


Fig. 1. "Manual Lincolnweld" fabricates this weldment at a speed of 50% to 75% higher than that of former method and eliminates cleaning.

Fig. 2. Mounted on radiograph carriage, "Manual Lincolnweld" gun boosts output of these box sections 200%.

Fig. 3. Speedy, concentrated heat of "Manual Lincolnweld" reduces distortion and cracking problems in welding of parts such as this base.

The above is published by **THE LINCOLN ELECTRIC COMPANY** *in the interests of progress.*
Write for free copy of "Manual Lincolnweld," Bul. 373. The Lincoln Electric Company, Dept. 97, Cleveland 1, Ohio.

Whatever you're welding

You get the same snappy,

G-E D-C WELDERS..

Yes, the General Electric WD-43 is a welder's welder. Rated at 300 amps (NEMA), it's designed to generate the ultimate in d-c welding performance. Whether its putting out its minimum or its maximum current, it stays right with the job with a peppy but easily controlled arc. And its extremely accurate current control is particularly useful with small diameter electrodes.

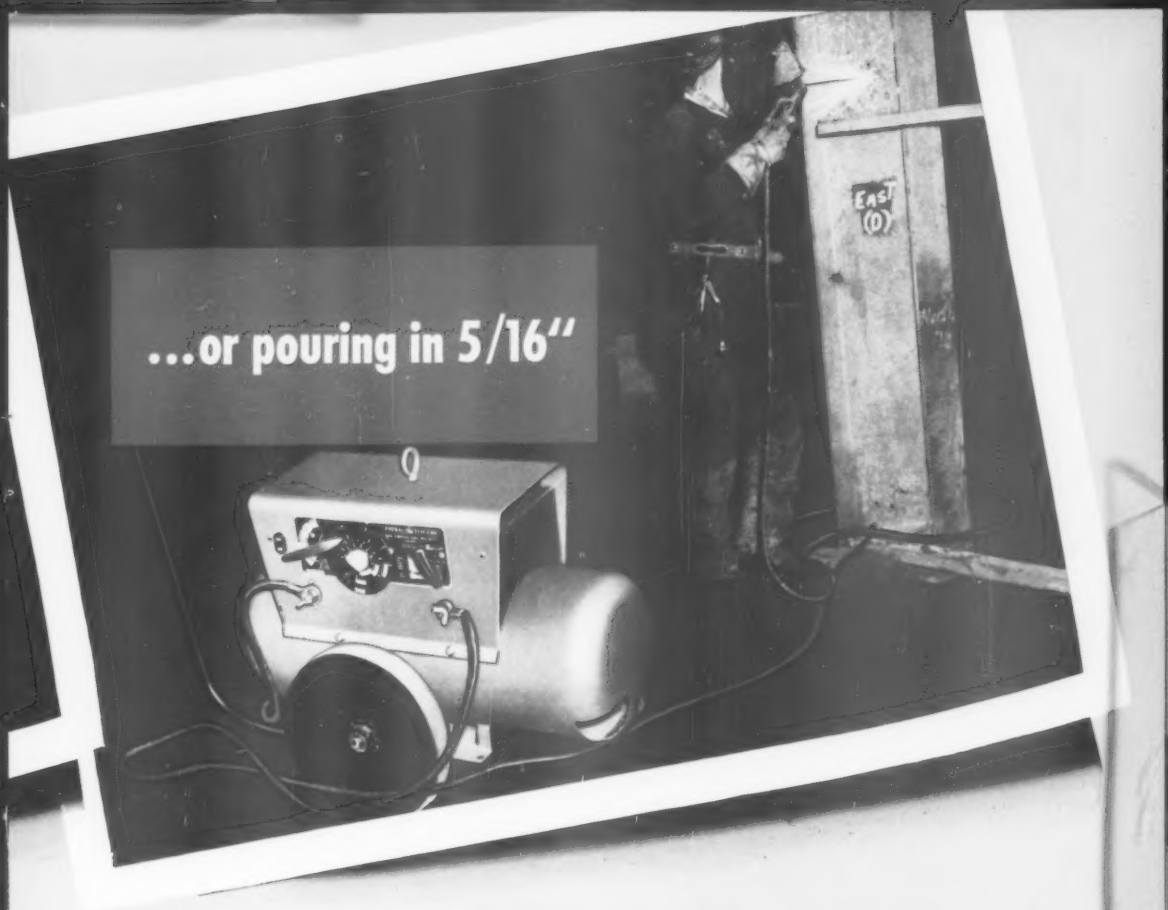
Its bigger and smaller brethren (the 400- and 200-amp ratings) are just as versatile. . . just as good at either extreme or anywhere in between on their broad current range. Their compact, functional design means extra welding performance with none of the dead-weight normally present in old-style d-c welders.

As motor-generator sets or in the engine-driven versions, G-E WD-40 series welders are operators' favorites everywhere they go. As one operator told us recently, "From the time I first struck an arc with this set, I was certainly impressed by the unusually steady stable arc."

You can put your confidence in

GENERAL ELECTRIC

ARC WELDERS...



stable arc...top-notch performance with

Single-dial dual control, an exclusive G-E feature, makes precise current setting a cinch every time. You simply set the dial and the welder does the rest. You'll also like the easy, inexpensive maintenance . . . the dependable, low-cost operation over a long "life-span".

ELECTRODES . . . ACCESSORIES . . . RENEWAL PARTS

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INCIDENTALLY, HAVE YOU SEEN "ARC WELDING AT WORK"? This new, sound-color motion picture depicts clearly the design and production advantages inherent in the three basic types of arc welding. Ask your G-E Arc-welding Distributor — or mail the coupon tomorrow.

Dept. 711-6, Apparatus Department
General Electric Company, Schenectady 5, N. Y.

☐ Send me bulletin GEA-4852 covering WD-40 series d-c welders

☐ I'd like to see "Arc Welding at Work"

NAME .....

COMPANY .....

ADDRESS .....

CITY ..... STATE .....

NEW LITERATURE

Lincoln Service Directory

The Lincoln Electric Co. has just issued an attractive service directory covering authorized field-service shops for parts, repair service, preventive service and rental service. One hundred twenty-four places are listed in practically every state of the union and in Canada.

Farm Welding Booklet

A new 24-page booklet, "87 Welding Ideas for the Modern Farmer," which features specific case histories on how farmers from practically every state have used their G-E. farm welders to repair, remodel and completely fabricate farm equipment, was announced recently as available from the General Electric Co., Schenectady 5, N. Y.

Listed as publication GEA-5053, this 2-color, pocket-sized booklet contains 87 illustrated case histories, a section on basic welding techniques and a page on selection of electrodes for any particular job.

The new publication, emphasizing the broad range of applications for welding on the farm, is an "idea" book, designed to show what can and is being done with welding by progressive farmers throughout the country.

Electrode for Steel Problems

Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y., has issued a six-page technical bulletin describing the application of their new Eutectrode 670 for all types of steel application, including manganese steel, cast steel, alloy steels, clad steels and stainless steels.

Micro Hardness Tester

Kent Cliff Laboratories of Peekskill, N. Y., has just issued *Bulletin K-49*, illustrating and describing the Kentron Micro Hardness Tester. The Kentron is a recent development in the field of micro hardness testing.

Copy available on request.

Hardsurfacing Guide

The Lincoln Electric Co., Cleveland 1, Ohio, has issued an attractive 4-page *Hardsurfacing Guide*. This bulletin briefly describes the numerous Lincoln electrodes for various applications of hard surfacing.

Fume Collectors

The Ruemelin Mfg. Co., 3860 N. Palmer St., Milwaukee 12, Wis., has just issued a new Bulletin No. *37-D*, illustrating the Ruemelin Fume Collectors. Five models are shown. The models include fume collectors for practically every fume removal application for welding. Copy available upon request.

Resistance of High-Nickel Alloys to Sulphuric Acid Corrosion

A new technical bulletin on the resistance of high-nickel alloys to corrosion by sulphuric acid has been issued by The International Nickel Co., Inc.

While the bulletin is technical in nature, it is written so that it can be readily understood by nontechnical as well as technical staffs of industries in which corrosion by this useful but highly corrosive agent is a problem.

Performance of over 30 different nickel-bearing materials in a wide range of services is discussed. Prepared by members of the Company's Corrosion Engineering Section, the bulletin contains 86 tables and 33 graphs and photographs in addition to text matter.

Problems involving such a wide range of operations from the pickling of steel to petroleum refining and textile processing are discussed. Known as *Technical Bulletin T-3*, it is available without cost through the offices of The International Nickel Co., Inc., 67 Wall St., New York 5, N. Y.

Industrial Cleaning Training

With industry today relying more and more on the recommendations of the engineers and specially trained representatives of its material and equipment suppliers as dependable sources of technical assistance, it is interesting to read about the comprehensive training course with which one manufacturer equips his field service specialists for this work.

Such a course is graphically described in a special 40th anniversary issue of *Oakite News Service*, house organ of Oakite Products, Inc., long-time suppliers of specialized industrial cleaning materials. A feature section of this issue shows how new field service representatives are trained in the latest technical developments and techniques of industrial cleaning and related operations. This is done by having the camera follow two trainees through the company's chemical research and service laboratories, into special lecture sessions by its field engineers, and through the many other phases of the course. Finally, an unusual photograph taken at the completion of the course shows a new service representative surrounded by some 750 lb. of demonstrating and testing equipment, technical literature and other service aids, ready to assume his new duties in providing industrial plants with the all-around technical advisory service demanded by today's complex cleaning and associated problems.

Readers interested in obtaining free copies of the special issue of *Oakite News Service* in which this training course is described, should address Oakite Products, Inc., 118 E. Thames St., New York 6, N. Y.

Booklet on Phos-Copper

The Westinghouse Electric Corp., has published a new 15-page booklet on extruded Phos-Copper, the uniform brazing alloy for copper, brass and bronze.

Extrusion and its contribution to better brazing is discussed at the beginning of the booklet. Then, eight methods of brazing with Phos-Copper are described—gas brazing, dip brazing, incandescent-carbon brazing, electric-furnace brazing, high-frequency induction, arc-torch brazing, carbon arc and spot welder.

The booklet discusses why Phos-Copper, with any recommended brazing method, saves material, time machines, man power and money. The reader also learns why Phos-Copper is better for manufacturing, installation work and maintenance.

The sizes and shapes of Phos-Copper, and also Brazaid No. 1 Flux and Fluxine paste are pictured and described. The last two pages contain diagrams which illustrate why "know how" makes good brazing easy and show proper joint designs.

A copy of the booklet (B-4198) can be obtained from the Westinghouse Electric Corp., P. O. Box 868, Pittsburgh, Pa.

High-Speed Photography

A 129-page illustrated booklet on high-speed photography has been prepared by the Society of Motion Picture Engineers. Consisting of papers presented at the symposium on high-speed photography during the October 1948 convention of the Society the booklet describes various high-speed cameras as well as techniques used by governmental and industrial agencies.

According to John H. Waddell, chairman of the high-speed photography committee, "These papers form the foundation for high-speed photographic work which is being continued at the first International Symposium on High-Speed Photography held at the Hotel Statler in New York on April 6, 1949. The subjects covered include not only motion picture photography but high-speed still photography as well."

Specific topics discussed in the new booklet include electrical flash photography and a new high-speed stroboscope lamp for high-speed photography, motion

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picture equipment for very high-speed photography, methods of analyzing high-speed photographs and the uses of high-speed photography in the armed forces, automotive and other industries and research.

The booklet may be obtained for $1.50 from the Society of Motion Picture Engineers, 342 Madison Ave., New York 17, N. Y.

Testing Machine Accessories

A new 12-page bulletin, *No. 261-A*, describes the supplementary devices which are used to adapt testing machines to the widest scope of testing conditions. These include several types of specimen grips, auxiliary equipment to widen the range of testing such as transverse test fixtures, cold bending fixtures and load-weighing air cells; accessories that extend some aspect of testing machine performance such as the controlled-temperature cabinet, furnace and load controlling accessories; and various testing conveniences. More than 30 illustrations show this equipment and how it is used. Copies are available from the Baldwin Locomotive Works, Philadelphia 42, Pa.

Protective Garments

Aljay Manufacturing Co., Inc., 1516 Callowhill St., Philadelphia 30, Pa., has issued a two-page bulletin describing their welders' aprons, sleeves and curtains. Copies sent upon request.

Industrial Elevators

Bulletin 10482, recently released, presents the comprehensive line of Barrett elevators and portable cranes. This 36-page book is profusely illustrated and contains full information and specifications on the various models in this line.

The elevators shown include portable hand-operated types with load capacities from 500 to 5000 lb., and lifting heights up to 36 ft., electric-operated portable types with capacities from 500 to 5000 lb., hand- and electric-operated telescopic portable types, barrel and drum elevators including tilting models, pallet types, four-post types, platform loading and balcony elevators, revolving base types and floor-to-floor elevators. Barrett portable cranes with fixed or revolving bases and electrically operated hoists are also shown.

The very newest Barrett elevators, the "Hundred" line—three standard models that meet a wide range of elevator requirements—are presented in an insert.

Described and illustrated in detail are the features which have figured in the widespread use of this make of elevators; such as the specially designed Barrett hoists for hand-geared and electric models, the cable safety device and other features which lend security; protected sheaves, the thermal overload switch, slack cable switch, automatic hinges, fully enclosed gears, grooved cable drum, direct-connected motor and arc-welded construction.

Bulletin 10482 will be mailed upon request by Barrett-Cravens Co., 4609 S. Western Blvd., Chicago, Ill.

Bulletin on 27% Chromium-Iron Offered by B & W Tube Co.

The properties and characteristics of 27% chromium-iron are comprehensively presented in a 30-page bulletin reprinted from an article by H. D. Newell, chief metallurgist of the Babcock & Wilcox Tube Co. It is illustrated with numerous photographs, tables and graphs prepared by the company's research department. Among the subjects covered are properties at elevated temperatures, impact properties and notch sensitivity, structural characteristics, embrittlement phenomena, working and fabricating and heat treating.

The bulletin, *TR-506*, will be sent free on request to the Babcock & Wilcox Tube Co., Beaver Falls, Pa.

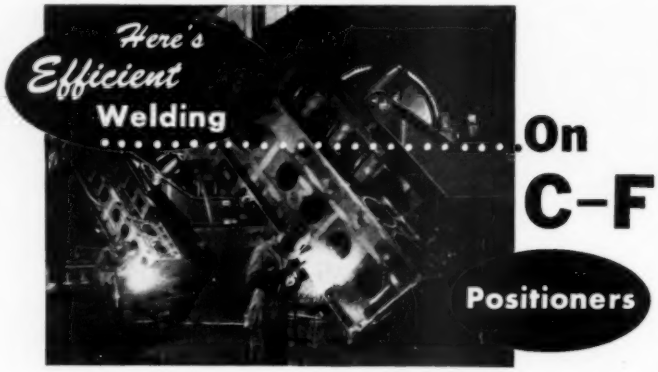
Tool Engineers' Handbook

The whole field of mechanical manufacturing industries and all the processes they employ in fabricating raw materials into finished products are covered in the *Tool Engineers' Handbook* scheduled for publication in July, according to an announcement by Harry E. Conrad, Executive Secretary of the American Society of Tool Engineers, 10700 Puritan Ave., Detroit 21, Mich.

Frank W. Wilson, editor of the *Handbook*, points out that the contents of this major reference work can be classified under the following major headings: (1) Planning and Control of Production, Inspection and Quality; (2) Materials and Machinability; (3) Casting and Extruding Operations; (4) Metal Cutting; Grinding; Finishing; (5) Metal Forming; (6) Welding, Gluing and Mechanical Joining of Materials; (7) Surface Finish and Protective Coatings; Peening; Balancing; (8) Gaging; Inspection; Testing; (9) Fixture, Die and Tool Design; Limited-Production and Master Tooling; (10) Machine Tool Controls and Feeding Devices; (11) Design of Threads; Gears; Bearings; Springs; Other Elements; (12) Mathematics; Physics; Reference Tables.

In preparing the *Handbook*, the American Society of Tool Engineers envisioned a completely new approach to meet needs which have developed in the transition of American industry from the era of the skilled craftsman who could produce an item almost single-handedly to the era of intensive specialization which demands the cooperative efforts of the many men of mass production.

Engineering handbooks commonly reflect the current mechanical patterns. The early handbooks naturally emphasized manual bench operations; dealt with the simpler basic types of machines and tools; scantily coordinated the product, the tool and the method. Such approach cannot serve the specialist of today, who requires detailed and highly specialized data.



When heavy, unwieldy weldments like these diesel crank cases can be quickly swung into any position so that every weld is made downhand —that's efficient welding!

Weldors spend more time welding—do better welding at lower cost when they work with C-F Positioners because these hand or power operated machines reduce positioning time to a minimum. Investigate the cost-saving advantages of C-F Positioners. They pay their way in any company.

Write for Bulletin WP24—an illustrated circular detailing the specific advantages of C-F Positioners

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Welder fatigue is reduced . . . slag is easily and *completely* removed with no secondary film, which means less cleaning, grinding and polishing time. Weld has corrosion resistance equal to that of the parent metal, with excellent mechanical properties. This all-new Arcaloy AC-DC stainless electrode is available in *all* chrome-nickel analyses . . . is packed in all-steel moisture-proof containers. Write for sample electrodes today!

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This new electrode is the result of Alloy Rods Co.'s continuous research and development which constantly improves standard electrodes, and develops new and better ones. For more specific information on this or any of the other Alloy Rods Co. electrodes for welding mild, stainless or tool steel, cast iron and various alloys, write today to: Alloy Rods Co., Dept. C-7, York, Penna.

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York, Pa.

To meet such needs, the *Handbook* was planned to integrate and present in one easy-to-use volume the widely scattered technical data developed by the Society's 18,000 members, the operating methods and standards of producing companies, national and associational standards, proceedings of engineering societies and institutes and published findings of the technical press.

"All this tested and proven know-how of modern manufacturing is contained in a 2300-page book," Wilson declared. "It thoroughly covers the mass-production fabricating industries."

One Electrode for Most Steel Problems

A universal steel-welding electrode that solves most steel-welding problems has been announced by Eutectic Welding Alloys Corp., New York, in the February issue of *The Eutectic Welder*. This 6-page house organ, with a circulation of over 225,000 is devoted to an interesting discussion of the great number of applications of Eutectrode 670 (DC) and Eutectrode 67 (AC) for arc welding. Adaptable to all types of steel welding, these Eutectic low-temperature welding alloys are also recommended for overlay, against frictional wear.

For further information, write to Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.

Air Reduction Announces New Reprint on Inert-Gas Welding

The Air Reduction Sales Co. has announced the availability of the new reprint entitled "Practical Aspects of Inert-Gas Welding" by H. A. Huff, Jr., and A. N. Kugler. This reprint was originally presented in the form of a paper before the 29th Annual Meeting of the AMERICAN WELDING SOCIETY and subsequently appeared in THE WELDING JOURNAL.

The 16-page article offers a comprehensive résumé of inert-gas, shielded-arc welding, including a description of the process, gases used, electrodes, straight vs. reversed polarity, d.-c. and a.-c. welding equipment, control of gas flow, techniques in welding stainless steel, aluminum, copper magnesium, steel and other metals. The text is augmented by 14 photographs and three tables.

Copies may be obtained without charge from Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y., or any Airco sales office.

Cast-Iron Electrodes

The Lincoln Electric Co., Cleveland 1, Ohio, has just issued a 4-page Technical bulletin *No. 465*, describing the different types of electrodes which this company manufactures for cast-iron welding. Properties and procedure, as well as typical applications, are included.

Price Increase on Textbook Manual of Design for Arc-Welded Steel Structures

The Air Reduction Sales Co., has announced that the price on their structural welding text book, *Manual of Design for Arc-Welded Steel Structures*, has been raised from $2.00 to $3.00. The company advised that higher printing and binding costs make the price increase necessary.

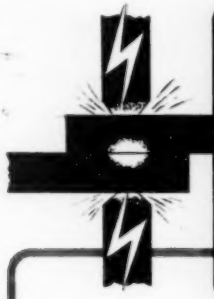
The manual, published in 1946, is now in its third printing. It was compiled by Air Reduction's LaMotte Grover, a recognized authority in the field of structural welding.

The book contains 300 pages of useful, up-to-date information covering fundamentals of design, materials, inspection, estimating and engineering control of welding and related operations.

Chapters are included to encompass electrode requirements, specifications for welded connections for all sizes of rolled beams and a series of diagrams for the rapid design of welded connections.

Manual of Design for Arc-Welded Steel Structures is based largely on standards of the AMERICAN WELDING SOCIETY, The American Institute of Steel Construction and upon reports of the Welding Research Council of the Engineering Foundation.

Copies of this valuable, attractively bound manual may be obtained from Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y., or at any one of the Airco sales offices located throughout the country. The book is sold with a 10-day money-back guarantee.



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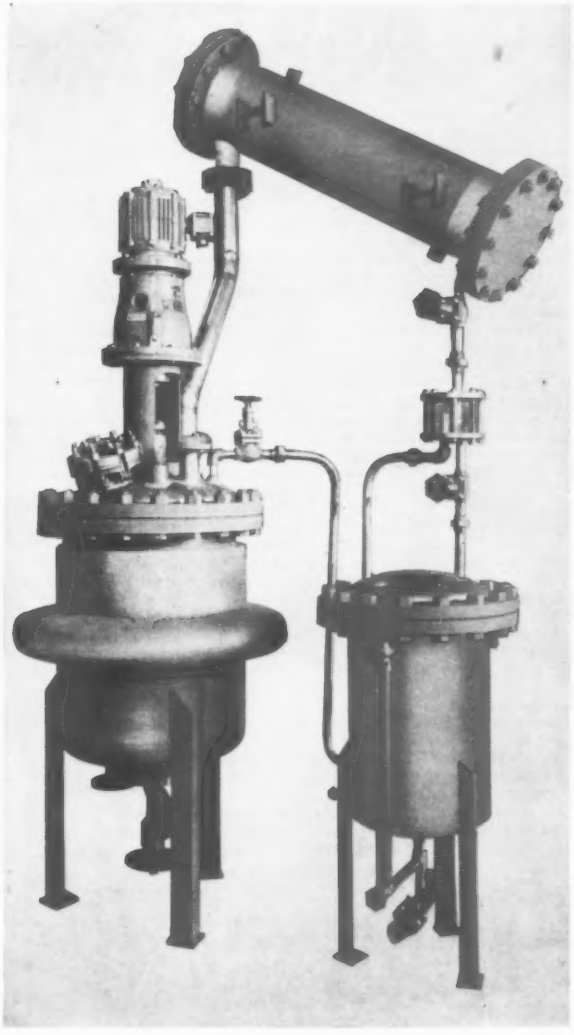

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Hobart Arc-Welder Specification Catalog

The Hobart Brothers Co., has released a new, 8-page, 2-color catalog containing illustrations, descriptions, dimensions and specifications on its complete line of "Simplified" arc welders, which includes electric motor driven d.-c. welders in six sizes from 150 to 1200 amp.; gasoline engine driven welders in four sizes from 200 to 600 amp.; a.-c. transformer type welders in four sizes from 180 to 500 amp.; welding generators only in three sizes from 150 to 300 amp.; gasoline engine driven welders with auxiliary a.-c. or d.-c. power generators; gasoline engine driven combination a.-c. arc welders and a.-c. power units in two sizes from 200 to 300 amp., and other models in all sizes for special arc-welding applications. Various features comprising the machine are individually illustrated and described. Also listed is a high-frequency stabilizer attachment for use with any standard a.-c. transformer type welder of 500 amp. or less. This attachment provides the essential high-frequency stabilization, with added convenience control features to greatly simplify inert-gas-shielded welding.

Catalog on Gas Welding Supplies

The publication of a new catalog on gas-welding supplies has been announced by Air Reduction Sales Co., manufacturers of oxyacetylene and electric arc-welding equipment.

The new catalog, the first of a projected series of ten, completely describes 19 different gas-welding rods, 8 different fluxes and includes a section on silver-brazing alloys plus a page devoted to carbon rods and carbon plates.

This easy-to-read, 16-page catalog is carefully indexed for ready reference. It is 8½ x 11 in. in size, with three hole punches for binder or loose leaf filing.

The text material offers descriptions of the mechanical properties of the various products and recommendations regarding their application. Data on lengths, packaging and available diameters are included for each welding rod.

Copies of this new catalog are immediately available at any Airco sales office.

Indentation Hardness Testing

Indention Hardness Testing, by Vincent E. Lysaght of the Wilson Mechanical Instrument Co., N. Y., is useful, factual and based on up-to-date industrial research practice. This new book covers the many problems involved in the hardness testing of metals and other materials. It describes the instruments in most common use—the Brinell, Rockwell, Scleroscope and Diamond Pyramid, as well as those used for specialized types of hardness tests. The author evaluates the advantages and disadvantages of each and gives complete specifications. He covers in detail the recent advances in the field and the work of present hardness committees of the leading technical societies.

Whether you are a metallurgist, a testing engineer, a machine operator or a student, you will find much of value in this complete story of hardness testing. The more advanced student and research investigator will find sufficient theory to afford a comprehensive basis for practical hardness testing. The plan, scope and simplicity of language make the book admirably suited for a text in schools offering courses in metallurgy.

Vincent E. Lysaght is a graduate of M.I.T. Since 1926 he has been in the Standardizing Laboratory of Wilson Mechanical Instrument Co., where he has dealt with all problems involving testing, development and research in hardness testing. He has written many articles and presented talks on the subject to many chapters of the A.S.M., A.S.T.M. and A.S.T.E.

Price $5.50. Published by Reinhold Publishing Corp., New York, N. Y.

Ultrasonics

Ultrasonics, by Benson Carlin of the Hillyer Instrument Co., and formerly Product Research Supervisor, Sperry Products, is a pioneer volume dealing with the many engineering aspects of the ultrasonic field, including the vital theory as well as a great deal of practical information never before published. Electronic considerations and outlines of circuits are specifically reviewed. Mechanical and electrical design of ultransonic systems are discussed, and illustrations are slanted to give definite guidance to the engineering worker in the field.

Important theoretical considerations have been presented in a manner suitable for application. Definitely slanted toward the practical rather than the purely theoretical worker, it contains particularly valuable information on testing materials, agitation, ultrasonic transducers and ultrasonic systems.

The astounding changes in various forms of matter brought about by ultrasonic vibrations of great intensity are explained, and interesting work being done in the biological, physical and chemical fields is discussed.

Price $5.00. Published by McGraw-Hill Book Co., New York, N. Y.

Oxyacetylene Welding and Cutting

Oxyacetylene Welding and Cutting, by Stuart Plumley, Formerly Chief Engineer, Smith Welding Equipment Corp., and revised and rewritten by T. B. Jefferson, Editor, *The Welding Engineer*, fills the need for a concise, easy-to-understand course of instruction in oxyacetylene welding and cutting technique. It begins with basic principles and proceeds step by step, to show you how to develop skill in handling both repair and production work. Changes and refinements that have been devised in the use of the oxyacetylene flame are explained and evaluated.

This guide covers all types of welding and cutting work: pipeline welding, flame-cutting steel and cast iron, brazing, lead welding, welding light metals, bronze welding and brazing, hard-facing, boiler and firebox welding, etc.

Particular stress has been placed on pipe welding and the newer techniques in the welding of alloy steels, aluminum, magnesium and silver brazing. Included, too, are chapters on job-shop operation and management and the business side of welding, written to assist the welding-shop owner to systematize his shop so that it will be more profitable to him.

Published by McGraw-Hill Book Co. May be purchased through the American Welding Society, 33 W. 39th St., New York 18, N. Y. Price $6.50.

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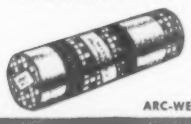

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NEWS OF THE INDUSTRY

A New Koven Jobbing Service

L. O. Koven & Brother, Inc., Jersey City, N. J., manufacturers of boilers, tanks, piping, special process equipment and weldments, announces the installation of a new 1000-ton Bliss drawing press at their Dover plant. The press is available for parts and subassembly production on a jobbing or contract basis.

This press is currently producing the heads for 275-, 550- and 1000-gal. fuel oil tanks and the generators for the Koven Waterfilm boilers.

Resistance Welding Supply Plant

The Weldaloy Products Co., Detroit, Mich., have purchased and are operating a new modern plant adjoining their present location.

According to James A. O'Grady, President, "Due to the ever-increasing use of resistance welding in industry, we have been forced to increase our production to meet customers' demands. The new plant is completely equipped with the latest machines and is used to produce special types of resistance welding supplies."

The metallurgical research and engineering divisions of Weldaloy are housed in the new plant and are under the direction of C. R. "Bob" Shroder.

Philadelphia Bronze and Brass Corporation

Charles E. Schley has been elected Chairman of the Board of the Philadelphia Bronze and Brass Corp., it was announced recently by the Board of Directors of that corporation.

Donald Bryden, associated with the Corporation 22 years, has been elected President and Director and Gordon E. Keim has been elected Vice-President and Director.

It was also announced that P. R. Mallory & Co., Inc., of Indianapolis, has acquired a financial interest in the Corporation. Dr. F. R. Hensel and Ray F. Sparrow, Vice-Presidents of P. R. Mallory & Co., Inc., have been elected Directors of Philadelphia Bronze and Brass Corp. Other Directors of the Corporation are George Schmidt, and Arthur Kitson.

For more than 12 years Philadelphia Bronze and Brass Corp., has been licensed by the Mallory Co., to supply castings and forgings of special Mallory alloy materials for various industrial applications. In addition, the Corporation has specialized in producing other nonferrous alloys of copper, nickel, chrome and aluminum, in the form of castings and forgings.

The Mallory Co., is one of the country's largest manufacturers of metallurgical products and electronic parts

In his announcement, Mr. Schley stated that these recent moves will strengthen and expand the sales organization, engineering facilities, and the financial position of the Philadelphia Bronze and Brass Corp.

Resistance Welding Sales

An increase of 14% in shipments of resistance-welding equipment has been reported for March 1949, as compared with the previous month, according to B. L. Wise, President, Resistance Welder Manufacturers Assn.

Shipments of resistance-welding electrodes—best guide as to the utilization of resistance-welding equipment—reached a new high for the year to date, being approximately 11% in excess of February and 8% ahead of the longer month of January.

The Engineering and Marine Exhibition, London, England, Aug. 25 to Sept. 10, 1949

The complete premises of Olympia, London, England, are reserved for the Exhibition which is the largest exhibition solely devoted to products of the mechanical engineering industry in the world.

This Exhibition first took place in 1906 and, except for the interruption of the two world wars, has taken place at biyearly intervals ever since. The 1949 Exhibition will be the seventeenth in the series.

The 1947 Exhibition broke all previous records for the number of exhibitors and visitors. The 1949 Exhibition, with over 600 exhibitors booking space, has already broken all previous records for size.

There has been a steady improvement in deliveries of United Kingdom engineering products as the nation has reorganized from a war to peace basis. Our engineering exports in 1948 were nearly 200% higher than the machinery export tonnage for 1938.

Stud Welding

Arrangements for the sale of patented Nelson stud-welding guns, gun parts, patented ferrules and patented flux-filled studs to KSM Products Corp., of Merchantsville, N. J., for resale by them in the United States, have been completed by the Nelson Stud Welding Division of Morton Gregory Corp., which has also licensed KSM to manufacture and sell slug-loaded studs in this country. KSM is not licensed, however, to make flux-filled studs, but can purchase them from the Nelson Stud Welding Division for resale.

The Nelson stud-welding process is used extensively in the shipbuilding, automotive, boiler, construction and other metal-working industries, both in the United States and in Europe, where Nelson products have a large acceptance.

Engineering and research facilities of Morton Gregory Corp., and its Nelson Division, maintain a continuous program for the improvement of stud-welding products and processes and the development of new applications, in the interests of its customers, distributors and licensees.

Ferguson Organizes Company

The Ferguson Welding and Pipe Line Engineering Co. of America, Columbus, Ohio, has been recently organized by D. O. Ferguson, an engineer registered under the Engineer's Act of Ohio as a Professional Engineer. Mr. Ferguson is also a member of the AMERICAN WELDING SOCIETY.

Mr. Ferguson has severed his connections with the Columbia Engineering Corp., the engineering subsidiary of the Columbia Gas System, Inc., where he was employed as an engineer for almost 21 years. His title was Chief Welding Engineer and Pipe-Line Construction Engineer.

In organizing the new company it is Mr. Ferguson's thought to make his services available to all pipe-line companies and pipe-line contractors particularly along the lines of pipe-line welding, welder qualification and procedure, investigation of weld or pipe-line failures, design and inspection of welding and pipe-line construction.

C. E. Smith Organizes the Resistance Welder Engineering Co.

C. E. Smith, 44 Union Savings & Trust Bldg. of Warren, Ohio, has organized the Resistance Welder Engineering Co., making available a consulting engineering service on resistance welding, power supply problems, power factor correction, 3-phase to single-phase conversion, electronic control design, rectifier engineering and service engineering.

Mr. Smith was formerly Chief Electrical Engineer of the Taylor-Winfield Corp., and enjoys an enviable engineering position in the resistance welding field. Previous to this position he was a design and development engineer on resistance welding controls for the Westinghouse Electric Corp. He is a Member of A.I.E.E. and AMERICAN WELDING SOCIETY, is the author of numerous technical papers on welding and served on various technical committees of R.W.M.A., A.I.E.E. and the AMERICAN WELDING SOCIETY.

NEW PRODUCTS

High-Temperature Tempilstiks°

Tempil° Corp. of 132 W. 22nd St., New York 11, announces the development of additional high-temperature ratings of Tempilstiks° (crayons) and Tempil° Pellets.

Both these temperature-indicating products can now, for the first time, be obtained in the temperature range between 1600 and 2000° F. This is of special interest because of the growing importance of higher operating temperatures in today's technology.

Beginning with 113° F., Tempilstiks° and Tempil° Pellets are now available in 12½-degree steps to 400° F. and in 50-degree steps from 400 to 2000° F.

Tempilaq°, the paint form of temperature indicator, is available in similar intervals from 113 to 1600° F. only.

Ohio Spot-Weld Nuts and Spot-Weld Screws

The recognition of the necessity of using all possible methods of bringing down costs of manufacturing all sorts of domestic, office and industrial appliances has focused the attention of industrial management on the reduction of fastening costs by the use of resistance-welding equipment.

As makers of fasteners and fittings for attaching to sheet steel surfaces by using projection welding, The Ohio Nut & Bolt Co. of Berea, Ohio, has received repeated requests to make a line of fasteners and fittings that could be attached by the spot-welding method. As is well known, spot-welding machines may be either the rocker-arm or press type. Spot welding is used in many instances to "tack" the fastener or fitting in place on products where the design throws no particular stress or load upon the welded joint.

A new bulletin illustrates seven sizes of spot-weld nuts ranging from No. 8–32 up to and including $^5/_{16}$–18 threaded hole now being made on a production basis and carried in stock at Berea. The bulletin also illustrates 63 production sizes of spot-weld screws for which tools are carried in stock for prompt shipment of production quantities.

Stock sizes of spot-weld nuts and production sizes of spot-weld screws are designed for use with the commercial thicknesses of sheet steel. Spot-weld nuts are made of low-carbon steel, specially made to give optimum welding quality and, likewise, the spot-weld screws are made either of low-carbon steel, high brass or stainless steel.

The savings obtained by using these new products run, in many cases, five times the selling price of the product replacing parts now being arc welded or brazed in position.

Electrode Holder

P. R. Mallory & Co., Inc., Indianapolis, Ind., announce a new bench-type welding electrode holder that offers complete versatility in adjustment, using standard packaged electrodes.

The new Mallory holder was specifically designed to save setting-up time and eliminate the need for bending and machining special tips.

Of especial interest to the welding industry are these outstanding features of the new holder. It has a full 180° range of head adjustment with positive locking in any position under full operating pressures. Heads are available for 30 or 90° electrode angle and the electrodes have positive, nonslip adjustment in the holder head over their entire length of 1¾ in. Because each electrode has a 90 and 30° welding face, in combination with 90 and 30° holder heads, a variety of positions is possible.

In addition to the many features listed, the new holders eliminate the need of handling rod stock for making up special electrodes. Electrodes are available in Elkaloy A and Mallory 3 metal, and are packaged in $^1/_{16}$, $^1/_8$ and $^3/_{16}$ in. diameters.

Light-Weight Torch

The Liquid Carbonic Corp., Chicago, announced their new model AV-10 lightweight welding and brazing torch. The

torch is all braze construction with the rear end designed for easy hose connections. It converts into a cutting torch by use of WC-10 cutting attachment.

"One-Split" Bus Design for Feed-In Duct

Square D Co., Detroit, has incorporated a "one-split bus" arrangement in its Feed-In Duct which greatly reduces voltage drop in the distribution of power over long distances.

The illustrated cross section is typical of a three-phase Feed-In Duct assembly. "One-split bus," *A*, with halves positioned on either side of the other two busses separated by insulator plates, permits close spacing and electrical symmetry important to reduction of both energy loss and voltage drop.

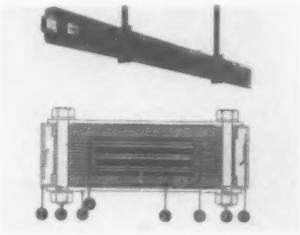


Illustration at top shows Square D Feed-In Duct in place. Lower illustration shows cross section of 3-phase Feed-In Duct assembly with "one-split bus" construction

Solid ebonized asbestos insulating plates, *B* and *C*, totally enclose the busses and have great mechanical and high dielectric strength. In addition, they are impervious to moisture and resistant to arcing. Surge clamps, *D*, and bolts, *F*, every 24 in., give structural and mechanical strength necessary to withstand 50,000-amp. "shorts." Steel channels, *E*, complete the housing.

A typical example of this reduced voltage drop characteristic is found in a 3-phase 1200-amp. section of Square D Feed-In Duct carrying full load at 70% power factor. The voltage drop is only 0.0000187 v. per ampere foot (2.24 v. per 100 ft. for 1200-amp. load).

Applications of Square D's Feed-In Duct include: (1) service entrances from transformer banks to distribution centers,

(2) vertical distribution in multiple story buildings, (3) low-drop transmission of large power blocks to utilization area and (4) supplying of resistance welder and other loads having normally low-power factor and high demand with a minimum voltage variation.

Feed-In Duct is available in 1200-, 1600-, 2000-, 3000- and 4000-amp. ratings, 2- and 3-wire single phase. Three-phase and 4-wire service for 600 v. or less. Carries the approval and label of Underwriter's Laboratories, Inc.

For further details, write Square D Co., 6060 Rivard St., Detroit 11, Mich.

Stainless Electrode and Container

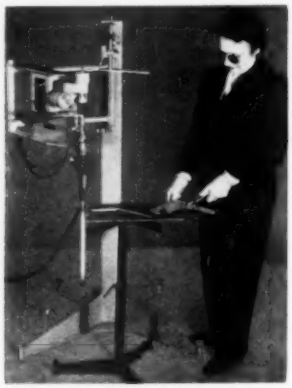
Alloy Rods Co., of York, Pa., has announced two new developments—a new Arcaloy a. c.-d. c. stainless electrode, and a new all-steel, moistureproof and greaseproof electrode container.

The new container is said to simplify stock problems and eliminate moisture damage to electrodes. It comes in easy-to-handle 5- and 10-lb sizes, designed to hold just the right amount of electrodes for typical welding jobs. The manufacturer points out that any electrodes left in the container after the welder has finished an immediate job are kept moisture free when the self-locking top is replaced.

The new Arcaloy a. c - d. c. stainless electrode is packed in the all-steel container. The manufacturer claims that tests have proved this new Arcaloy a. c. - d. c. produces the cleanest welds in stainless welding history. It is available in all chrome-nickel steel analyses.

Contour Cutter

Heath Contour Cutter, manufactured by Heath Engineering Co., Fort Collins, Colo., provides the versatility and accuracy of an expensive pantograph machine at a fraction of the cost. A standard acetylene machine cutting blowpipe is employed to automatically reproduce a desired pattern in any sheet steel or heavy-plate steel quickly and with uniform accuracy. Duplicate flat-shape forms, cut to a predetermined pattern, can be produced at low cost for many metal fabricating operations. The Heath Contour Cutter is simple to operate, fast, accurate and is readily adaptable to mass production techniques. Master patterns can be quickly changed, working edges are clean, smooth-fitting and ready for welding.



The Heath flat-shape flame cutter is sturdy, compact and precision engineered to satisfy the exacting requirements of flat manufacture in shop and factory. The "brain," or pattern-tracing finger, incorporates a variable speed, magnetic rotor which exactly follows the master pattern in producing flat-shape duplicates in any quantity desired. Optional operating speed permits adjustment to accommodate any gage steel or production procedure; such as stack cutting, etc. Rotor diameter of $\frac{1}{4}$ in. insures accurate pattern tracing of acute and obtuse angles, obverse and reverse curves, slots and projections. Flexible range of practical pattern sizes includes $\frac{3}{8}$-in. holes to 5-ft. diameter shapes.

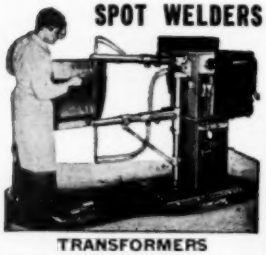
All moving parts are sealed, ball-bearing mounted and require no lubrication. Two bubble levels and four leveling screw adjustments in the base give true horizontal operation.

Shortstub Electrode Holders

"Lifeguard" is a new insulation material which completely covers the electrode gripping head of Bernard "Shortstub" electrode holders. In that the unique design of shortstub holders makes it possible to deposit the total fluxed length of welding electrodes which results in the lowest possible electrode waste, the new insulation material was developed to withstand the direct heat of the arc when the last inch of the electrode is being deposited. Laboratory and field tests prove that the new "Lifeguard" insulation will withstand these high temperatures and will wear two to four times longer than ordinary types of material generally used for this purpose.

The new insulation also has an extremely high resistance to impact and will not chip or crack regardless of how rough the holder is handled. In that all metal parts of the Shortstub electrode holders are completely covered with insulation they can be handled without danger of electric shock even when used in wet areas.

Shortstub electrode holders with Lifeguard insulation are manufactured by Bernard Welding Equipment Co., 741 E. 71st St., Chicago 19, Ill.



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YOUR GUIDE TO BETTER WELDING

HERE is a handy data sheet that can help you get good results in Gas Welding, Arc Welding or Furnace Brazing. It lists the different types of jobs you might want to do and shows which Revere Welding Rod will give best results in each use. This data sheet is free for the asking—write for your copy today.

Revere Welding Rods are among the many copper and copper alloy products made by Revere Copper and Brass Incorporated. As with other Revere products, constant research, modern production equipment, and rigid quality control have made Revere Welding Rods unsurpassed in quality and performance.

Revere Welding Rods include: Revere 456 Low-Fuming Bronze Welding Rod, Revere Bronze 380, Manganese Bronze, Herculoy, Phosphor Bronzes, Brass (Brazing Rod), Silicon Deoxidized Copper and Electrolytic Copper. All come in 100-pound cases or in 25-pound cartons, net weight, and are stocked by Revere Welding Rod Distributors in all parts of the country.

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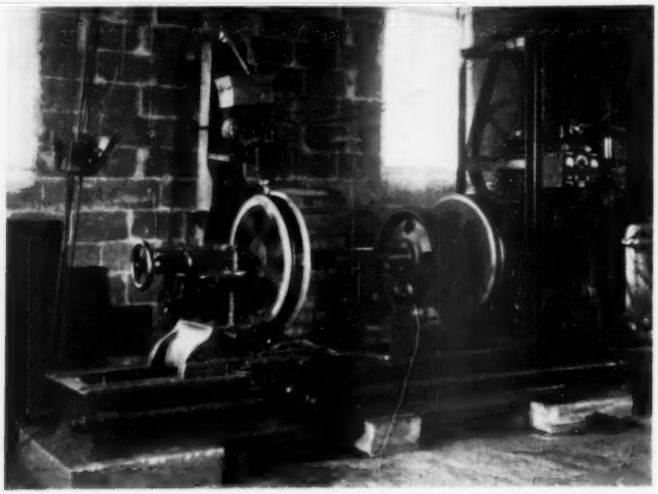
* * *

Mills: Baltimore, Md.; Chicago, Ill.; Detroit, Mich.; New Bedford, Mass.; Rome, N.Y. Sales Offices in Principal Cities, Distributors Everywhere.



Cost of Rebuilding Wheels Cut 30%

Formerly it required two welding operators to rebuild a set of mine locomotive wheels in one day—by the manual arc process. Using the Unionmelt process, one operator can rebuild from 5 to 8 wheels per day, depending on the amount of wear.

The welding installation consists of a standard Unionmelt U welding head mounted on a stationary column. To avoid interruptions, 150-lb. large-size coils of welding rod are used. The hopper on the machine is filled by gravity from an auxiliary hopper holding 500 lb. of granular Unionmelt welding material (not shown in the photograph).

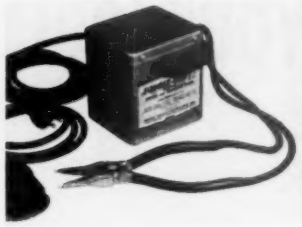
The mine wheels are mounted in an old lathe and rotated under the welding head at the proper speed. An average of approximately 25 lb. of material is deposited over the 3-in. face of the wheels in a layer $1/2$ in. thick.

Welding time was reduced from an average of 3 hr. by hand build-up to 70 min. by the automatic Unionmelt process. Machining operations are reduced as much as 50% and tool breakage due to hard spots is practically eliminated. Due to the continuous rotation and the amount of material applied, no further heat treating or annealing is required.

Electric Soldering Pliers

Electric soldering pliers, employing the current-resistance principle introducing a faster and more positive method of soldering, have recently been placed on the market by the Durst Manufacturing Co., at 11110 Cumpston St., North Hollywood, Calif. These pliers which guarantee freedom from "cold-joints" cut soldering labor in half. Instantaneous heat requires no tinning, heat elements or tips. Tool is always cool.

The Durst electric soldering pliers are designed for wiring and soldering. They are especially adaptable to compact assemblies. The wires or parts to be soldered are held by the pliers, the foot switch is depressed for an instant, heating the wires or part sufficiently to melt the solder. The current-resistance principle employed heats the work instantly only at the point of contact. The pliers remain cool at all times and the resultant soldered joint with this "heat in the work" process requires less solder, makes a solder-weld at a localized point without heating the entire terminal, scorching or burning insulation, nor shrinking plastic insulation.



Low Melting Aluminum Welding Alloy

Through pioneering in the field of joining aluminum without fusion of base metal, Eutectic Welding Alloys Corp., New York, offers to Industry another new Eutectic development in the form of the Eutec-Aluminum-Weld Economizer.

Rene D. Wasserman, President, announces that this compact, handy Economizer kit is specifically designed for torch welding of aluminum at temperatures far below melting point of aluminum. For greater strength welds with no distortion, Eutec-Aluminum-Weld will answer the needs of all those working with aluminum.

Designed as an extremely thin-flowing alloy for use with special Eutector Flux, lap and slip type welds on aluminum become a simple task. Eutec-Aluminum-Weld, because of its extremely fluid character, bonds readily to the surface, resulting in a clean, smooth weld. It is most suitable for joining thin parts . . . a job that would be impossible with higher melting alloys. The finished weld is corrosion-resistant and has excellent color match. No after-machining is required. No waste of material is involved. Packed in coil form in this container, with a jar of Eutector Flux in the bottom section of the Economizer, no time is wasted hunting for alloy and flux. Both are in one container, for ready use.

NET MONTHLY ADVERTISING RATES

Black and White — **Effective July 11, 1947**

Space	One Insertion	Three Insertions	Six Insertions	Twelve Insertions
*Full page	$185	$165	$150	$140
Two-thirds page	130	120	110	100
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Quarter Page	60	58	55	50
Eighth Page	40	35	30	28
*Inside Preferred	205	185	170	160

10% Extra for bleed full pages. Color $65 extra per color added

Agency Commission —15%
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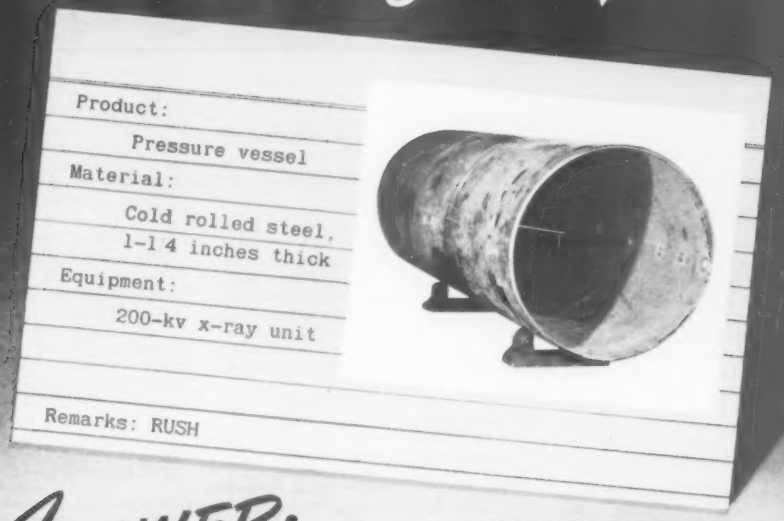
What's the right X-Ray film?

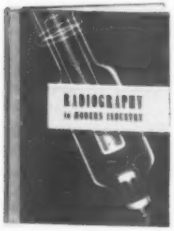


ANSWER:

KODAK INDUSTRIAL X-RAY FILM, TYPE K

The wall of the tank was thick—the kilovoltage available was low. And the customer was impatient for delivery. So the radiographer did this job with Kodak Industrial X-ray Film, Type K.

This film, in contact with lead foil screens, has sufficiently high speed to allow reasonable exposure with equipment of moderate power. The good definition so obtained is added assurance that significant weld irregularities will not be missed.

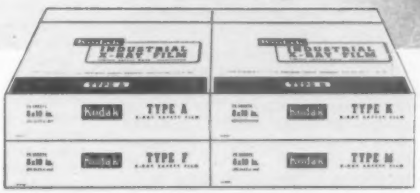


RADIOGRAPHY IN MODERN INDUSTRY

A wealth of invaluable data on radiographic principles, practice, and technics. Profusely illustrated with photographs, colorful drawings, diagrams, and charts. Get your copy from your local x-ray dealer—price $3.00.

Radiography...

another important function of photography



A TYPE OF FILM FOR EVERY PROBLEM

To provide the recording medium best suited to any combination of radiographic factors, Kodak produces four types of industrial x-ray film. They furnish the means to check welds efficiently and thus extend the use of the welding process.

Type K has medium contrast with high speed. For gamma ray and x-ray work where highest possible speed is needed at available kilovoltage without calcium tungstate screens.

Type F provides the highest available speed and contrast when exposed with calcium tungstate intensifying screens. Has wide latitude with either x-rays or gamma rays, exposed directly or with lead screens.

Type M provides maximum radiographic sensitivity, high contrast, and exceptional detail under direct exposure or with lead foil screens. It has extra fine grain and the speed is adequate for examination of light alloys at moderate kilovoltage and for much million-volt radiography.

Type A offers high contrast with about three times the speed of Type M, but with slightly more graininess. Used direct or with lead foil screens for study of light alloys at low voltages, and of heavy steel parts at 1000 kv.

EASTMAN KODAK COMPANY
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Kodak

abstracts of CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies may be obtained for 25c from the Commissioner of Patents, Washington 10, D. C.

2,465,456—Welding Mechanism—Frederick H. Johnson, Pleasant Ridge, Mich.

The apparatus covered by this patent includes a unitary member provided with a cylindrical bore that receives a piston formed from electrically insulating material. The piston has a piston rod secured thereto with one end extending outwardly of the bore. A single block of electrically insulating material is secured within the bore and has a passage therethrough for slidably engaging with the piston rod.

2,465,503—Welding Electrode—Gorham W. Woods, Cleveland, Ohio, assignor to The Lincoln Electric Co., Cleveland, Ohio, a corporation of Ohio.

Woods' electrode includes an elongate metal tube formed from a metal strip which has inner and outer circumferentially overlapping edges. The outer of the edges is turned radially outwardly to form a continuous integral rib extending longitudinally of the electrode, and an outer coating of flux is positioned on the electrode that leaves the rib exposed.

2,465,596—Arc-Welding System—George G. Landis, South Euclid, and Norman J. Hoenie, Cleveland Heights, Ohio, assignors to The Lincoln Electric Co., Cleveland, Ohio.

This patented welding system includes a transformer the secondary of which is connected to the welding circuit. An independent, normally closed circuit is provided and has a supplemental winding included therein adapted to induce additional flow of current in the secondary winding of the transformer. A control relay is provided in the welding circuit for opening the independent circuit and cutting out the supplemental winding in the transformer after a predetermined current flow is set up in the welding circuit.

2,465,750—Composition for Preparing Aluminum and the Like for Welding—Arthur A. Reid, Westfield, N. J. Assignor to Reid Engineering Co., a corporation of New Jersey.

Reid's patent is on a liquid composition that consists of substantially equal parts by volume of orthophosphoric acid, nitric acid and ammonia.

2,465,879–2,465,880—Portable Spot Welder—George J. Kauder, Brooklyn, N. Y.

This novel spot welder includes as one feature of the apparatus a nosepiece which is pivotally mounted upon an upper front portion of the frame and which supports the movable electrode of the apparatus. A carrier handle is provided for the welder and a pivotal handle portion is also provided and is associated with and connected to the pivotal nosepiece whereby movement of the movable handle section can control the movement of the movable electrode carried by the nosepiece.

2,466,497—Automatic Welding Machine—William E. Smith, Detroit, Mich., assignor to The Midland Steel Products Co., Cleveland, Ohio, a corporation of Ohio.

This welding apparatus includes a carriage which has a welder slide mounted on the carriage. The carriage is moved through a longitudinally directed cam and a welder is provided on the welder slide and cam means connect the welder to the movement control means so that the welder slide is first moved in the direction of movement of the carriage and then is moved in the opposite direction while the carriage is constantly propelled in one direction.

2,466,562—Art of Welding Plate and Propeller Blade Construction—Arthur W. Steinberger, Elizabeth, N. J., assignor to Curtiss-Wright Corp., a corporation of Delaware.

In this welding method, the elements to be welded together are positioned in a desired relation after which a moldable material is applied to the article and conformed to the final shape of the weld desired and a formable refractory thermal setting composition is then applied to the moldable material. Next the associated article and materials are heated which sets the refractory material and ultimately fuses or melts the moldable material which then can be drained from association with the members. Next weld material is applied to the article to fill the void left by moldable material flowing from its original position after which the refractory composition can be removed from the elements after the weld metal has frozen in position.

2,466,761—Resistance-Welding Apparatus—Paul Cahen and Gustavo Adolpho Marinho Lutz, Rio de Janeiro, Brazil.

This welding apparatus relates to a special type of a transformer which has a single-turn secondary winding which is rotatably mounted on the core and which comprises a pair of circumferentially split annular welding electrodes. A circumferentially split and annular conductor is mounted between and mechanically secured to each electrode and other means respectively connect electrically one electrode to one conductor to provide at least one complete secondary winding turn about the core. The secondary winding is completed by the work to be welded.

2,466,886—Arc-Welding Tool—Peter N. Frade, Detroit, Mich. Assignor to C. E. Phillips & Company, Detroit, Mich., a corporation of Michigan.

This patent is on a carbon-flame electric welding tool which includes telescopically and concentrically positioned conductors that have an insulator tube positioned therebetween. Holders for the electrodes extend laterally from one end of each of the conductors and a handle is secured to the opposite end of one of the conductors. Resilient means are provided for urging the conductors in a direction to separate the electrodes from each other and means are operable by hand for relatively moving the conductors to contact the electrodes.

2,467,311—Method of Electrically Welding Plowshares—William W. Hudson, Moline, Ill., assignor to Deere & Co., Moline, Ill., a corporation of Illinois.

This patent relates to a special welding application wherein two metal blades are positioned at acute angles with relation to each other at a corner to be formed between such members. The adjacent or contacting metal portions of the members are fused together after which a filler metal is deposited at the outermost portion of the corner formed between the members.

2,467,321—Welding Apparatus—Chester F. Leathers, Detroit, Mich.

Leathers' apparatus relates to a high-amperage, low-voltage electrical system wherein a plurality of energy using elements are provided and have electrical energy supplied thereto. Circuits connections are provided between the source of electrical energy and the energy using elements and a plurality of branch circuit portions are connected to the elements. Contactors are provided for controlling the current flow from the source of energy

to the elements and a plurality of individual contactors are connected in the corresponding branch portions of the circuit and individually responsive to the elements to which they are connected.

2,467,379—Welding System—Harold J. Graham, Boston, Mass., assignor, by mesne assignments, to Graham Mfg. Corp., Detroit, Mich., a corporation of Michigan.

The patented welding apparatus includes a plunger casing which is slidably carried by, and insulated from, a guide casing. The plunger casing has a percussion block carrying a work holder secured thereto and slidably engaging a working plunger adapted to impinge upon and make electrical contact with the percussion block. The working plunger is urged toward the percussion block when the guide casing is moved toward the plunger casing. Latching means normally engage the plunger and secure it to the plunger casing and they extend into the path of a portion of the guide casing to be released by relative displacement of the casing against the force urging the plunger toward the percussion block.

2,467,516—Method of Electrically Welding Box Sections—Einar Almdale, Rocky River, Ohio, assignor to The Midland Steel Products Co., Cleveland, Ohio, a corporation of Ohio.

This welding method relates to the formation of a box section from two electrically conductive channel sections by overlapping same and welding together the flanges thereof. The outer flanges are deformed to provide means for supporting the inner flanges against inward deflection, and the welding action is secured by the combined effect of inwardly exerted pressure and electric current.

2,467,536—Portable Welding Device—Hans Alfred Schlatter, Zurich, Switzerland.

This patent covers a special welding combination wherein a clamping means including a bridge for bridging the spot to be welded and comprising two longitudinal bearer members and two yoke pieces is provided. The bridge includes walls forming a stationary and a displaceable clamping chamber within which the ends of workpieces to be welded are locked. Two contact jaws are supported on a chassis member which also supports a welding transformer. Each jaw is adapted to grip one end of each of the workpieces.

2,467,628—Welding Apparatus—Louis R. O'Neill, Warren, Ohio.

An electric-resistance welding apparatus of the type in which the apparatus serves as a means for applying pressure to the parts to be welded is disclosed by this patent. The construction provides two relatively movable members for supporting electrodes and fluid pressure means are provided for moving one of the electrodes with relation to the other.

2,467,629—Spot-Welding Gun—Louis R. O'Neill, Warren, Ohio.

O'Neill's second patent relates to details of the construction of the piston and cylinder assembly for controlling a position of a movable electrode with relation to a stationary electrode, which construction is of the general type covered in his patent No. 2,467,628.

2,467,636—Electrode Die for Welding Apparatus—Bernard Stoudt, Valley Stream, and Anthony Giordano, Brooklyn, N. Y., assignors to Ames Spot Welder Co., Inc., Brooklyn, N. Y., a corporation of New York.

A special type of a die is covered in this patent, which die is adapted to form a contact tip on an electrode.

2,467,723—Stud Welding Apparatus—Kenneth Frederick Barlow, Preston, England, assignor to The English Electric Co., Ltd., London, England, a British company.

In this patent, a stud-welding gun is disclosed and it includes a sleeve that is slidably positioned within a cylindrical body portion. Clutch means are positioned within the sleeve and a spindle projects from the sleeve for engagement with the clutch means. Spring means are provided for biasing the sleeve with relation to the body portion and additional spring means by which the sleeve is biased with relation to the spindle.

LIST OF NEW MEMBERS

April 1 to April 30, 1949

ANTHONY WAYNE

Schlatter, Carl C. (B)

BIRMINGHAM

Ray, Marvin (C)

BOSTON

Foster, Francis E. (B)

BRIDGEPORT

Nelson, Alfred (C)
Nelson, Robert A. (C)

CHATTANOOGA

Jackson, Herbert Dan (C)

CHICAGO

Lifton, W. O. (B)
Schneider, H. E. (C)

CLEVELAND

DeJohn, Ben (C)
Kotchian, John F. (C)

COLUMBUS

Eddins, Mike Whiteg (D)
Mogren, Roy (D)

DETROIT

Adams, Emil (C)
Arnold, L. E. (B)
Bacher, Frank (C)
Barrett, J. G. (C)
Bellville, Glen (C)
Bird, Harrison, Jr. (B)
Bogard, Earl J. (B)
Breen, Mervyn (B)
Cartmill, Samuel (C)
Clark, Archer D. (C)
Coburn, Robert H. (B)
Davis, Samuel G. (C)
Files, Claude I. (C)
Gulick, Michael (C)
Hodgdon, Lester (C)
Houtsma, J. H. (C)
Jernigan, Glen W. (C)
Karl, Robert L. (B)
Keefer, Ernest G. (C)
Keene, John A. (C)
Krug, Charles (B)
Kucharczyk, Joseph J. (B)
Lamont, William D. (B)
Leimeter, John (C)
Lillard, L. F. (C)
McLaren, Gordon (B)
Menzies, William P. (B)
Miller, C. A. (B)
Odren, Glenn (B)
Paxton, Charles F. (C)
Plummer, William R. (B)
Poole, L. C. (B)
Rapp, John (C)
Reiss, Gordon F. (C)
Rocland, Robert (C)
Rogala, Edward (C)
Soi, Lee Lin (C)
Tarter, Wallace (B)
Weed, H. D. (B)

Indiana

Bowman, Macy (B)
Isgrigg, Gilbert E. (B)
Kuhn, Charles (B)

INLAND EMPIRE

Reynolds, E. L. (B)

KANSAS CITY

Smith, Martin W. (C)

LONG BEACH

Ebberheimer, Howard (B)

LOS ANGELES

Guy, G. M. (B)
Kellerman, Ludwig B. (C)

MAHONING VALLEY

Boley, Frederic, William (C)

MARYLAND

Donnelly, James H., Jr. (C)
Lanmon, Paul A. (C)
Roberts, Joseph A. (C)

MILWAUKEE

Burris, Van W., Jr. (B)

Typical repair on 275-hp. Diesel truck engine. A broken engine block was repaired by applying a patch with Ni-Rod welding electrodes. Fourteen months later, the block is still in service.

IN the open-pit nickel mines at Copper Cliff, Ontario, Diesel trucks haul 32-ton ore loads up steep, winding roadways. After several thousand hours of this severe service, failures develop in castings and engine parts.

A serious type of failure is the cracking of cast iron cylinder blocks. New engine blocks cost $644.09 each ... a price that makes the prospect of repairs very attractive.

In the past, damaged blocks have been repaired by oxy-acetylene welding, a relatively critical and time-consuming process. But recently, repairs have been made with metal-arc welds, using Ni-Rod* electrodes. This technique has been completely successful, and the use of Ni-Rod electrodes has given excellent weld quality and has cut welding time.

Here are three typical case reports on repairs made with Ni-Rod:

"1. Block broke in crank chamber after 9381 hours of service. A patch was welded in with Ni-Rod. Since the repair, the block has operated 2064 hours and is still in good condition. Cost of welding was $12.75.

"2. Crank shaft failed after 1746 hours. The broken end engaged the main bearing shells, turning them in the block, heavily scoring the saddle. Repairs were made by machining the bearing area to .100-inch oversize, building up with Ni-Rod, and finally machining to correct size. This prolonged the engine life by 4087 hours. Cost of the entire repair was $40.60.

"3. Crank shaft failed after 4540 hours, causing damage similar to that described in Case 2, above, and was repaired the same way. The engine is still in operation 1369 hours after the repair. The cost of repair was $42.50."

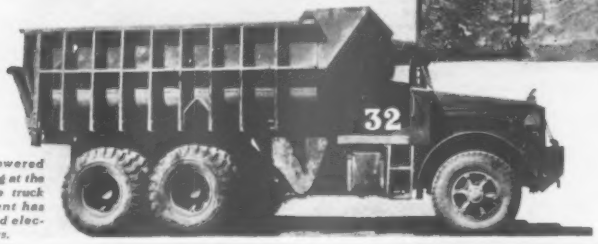
SAVED . . .
HOURS MORE SERVICE
from truck engines repaired with NI-ROD

The three blocks described have a total replacement value of $1,932.27. Subtracting the repair costs, there is a net saving of $1,836.42, and a gain of more than 7520 hours of operating service.

Maintenance stories such as these...three of hundreds in our files...show why 4 out of 5 shops re-order Ni-Rod. once they've tried it. If you are not yet familiar with Ni-Rod's outstanding advantages, why not order a package today? Your nearest INCO distributor stocks Ni-Rod in 3/32", 1/8", 5/32", and 3/16" diameters.

Send for your free copy of: *"NI-ROD—A New Electrode for Any Cast Iron Welding."*

The Frood Stobie Mine, Copper Cliff, Ontario, operated by The International Nickel Company of Canada, Ltd.



One of the Diesel-powered trucks used for ore hauling at the Frood Stobie Mine. The truck maintenance department has standardized on Ni-Rod electrodes for cast iron repairs.

HERE'S WHAT NI-ROD GIVES YOU

in performance

- Stable arc in all positions
- Smooth bead contour
- Excellent wash
- Easy slag removal
- Preheating seldom required
- Works on both AC and DC

in weld quality

- High-strength deposit
- Easy machinability
- Thorough fusion
- Freedom from cracks and porosity
- Close color match

in usefulness

- General repair and maintenance of cast iron parts, including build-up of worn surfaces
- Quick remedy for minor flaws in new castings
- Correction of machining errors
- Assembling cast iron to steel

EMBLEM OF SERVICE INCO NI-ROD TRADE MARK

THE INTERNATIONAL NICKEL COMPANY, INC.

67 Wall Street, New York 5, N. Y.

*Reg. U. S. Pat. Off.

Cook, R. H. (C)
Wogsland, Neal C. (D)

NASHVILLE

Henshaw, Richard A. (B)

NEW JERSEY

Branthwaite, Wilfred (C)
Chapin, Henry J. (C)
Giangrande, George (C)
Labaugh, William (C)
LaFrance, Berl (C)

NEW YORK

Axthelm, Everett W. (B)
Boltz, D. C. (B)
Kelpien, Theodore M. (C)
Mainelli, John (C)
Marino, A. J. (B)
Sandler, William (B)
Sands, John W. (C)
Schoening, Carl H. (C)

NIAGARA FRONTIER

Bender, Henry C. (C)
Clemens, Frank C. (B)
Engelman, R. C. (B)
Farwell, Kerlin R. (C)
McMullen, George T. (B)
Moser, R. F. (B)
Sage, Derreth C. (C)
Summers, Floyd M. (C)
Yeager, James P. (B)

NORTHERN NEW YORK

Slaughter, Gerald M. (D)

NORTHWEST

Grabner, Walter J. (C)
Pitzl, Joseph (B)
Sahly, Henry (C)

NORTHWESTERN PA.

Chester, Elbert N. (B)

PEORIA

Callahan, James (B)

PHILADELPHIA

Benker, Charles H. (C)
Buerkel, David H. (C)
Grantland, George L., Sr. (C)
Hagerty, H. T. (B)
Kennedy, Eugene (C)
Sanford, Edward R. (C)
Yeager, William W. (B)
Zuick, Albert J. (C)

PITTSBURGH

Berger, John N. (B)
Creutz, Prof. E. (B)
English, R. H. (B)
Enzian, George H. (C)
Gray, Robert (B)
Harvard, Jack (B)
Ludwig, Howard C. (C)

PORTLAND

Anderson, Jack V. (B)
Johnstone, Thomas A. (B)

ROCHESTER

Santangelo, Bennie J. (B)

ST. LOUIS

Burdge, David V. (C)

SAN FRANCISCO

Boyle, W. F. (B)

SOUTH TEXAS

Ferrell, Thomas G. (C)
Holt, Walter Granville (C)
Parrott, H. C. (C)
Sprow, Donald L. (C)

TOLEDO

Seubert, H. M., Jr. (D)

WASHINGTON

Fox, J. C. (C)

YORK-CENTRAL PA.

Renshaw, C. F. (B)
Smith, Albert J. (C)

NOT IN SECTIONS

Berg, J. ter (B)
Bouillon, Rene (C)
Drevitson, Wesley B. (C)
Fairman, George F. (C)
Haller, Robert Clifton (C)
Havlicek, John (C)
Housz, A. J. Ingen (B)
Kelly, J. J. (C)
Longworth, Dennis (C)
McDaniel, Zee M. (D)
Michel, Eugene (D)
Reeves, Dale M. (D)
Sarazin, Jean L. (B)
Woolard, Robert F. (C)

Members Reclassified

During Month of April

DETROIT

Brown, Carroll (C to B)

NORTHERN NEW YORK

Richter, Charles R. (C to B)

SECTION ACTIVITIES

Prepared by C. M. O'Leary

Anthony Wayne

The April meeting of the Anthony Wayne Section was held on Friday the 22nd at the Fort Wayne Chamber of Commerce Building. Following a buffet dinner which started at 6:30 P.M., the members and their guests were feted to a half-hour program of both old and new barbershop songs presented by the Reddy Kilowatt Barbershop Quartet.

George Laws, Chairman, then announced that the May Meeting would be in the form of a dance and card party to be held at the Orchard Ridge Country Club which would give the members' wives a chance to enjoy an A.W.S. Meeting.

Chairman Laws then introduced Paul G. Feld, district sales and service supervisor for Handy & Harman, who in turn introduced the technical speaker of the evening, R. J. Metzler of Handy & Harman's engineering division, New York City.

Mr. Metzler's subject "Design for Silver Alloy Brazing" was very well covered in a "down to earth" manner. He stressed and explained thoroughly such points as: proper choice of materials, proper heating methods of particular jobs, importance of joint preparation and fit-up, need for cleanliness of joint, suitable application of flux, proper silver-brazing alloy to be applied, and flux removal after braze is completed. He backed up his points and contentions with illustrative slides. Following his address, a color sound film "The Fundamentals of Silver Alloy Brazing" was shown and a "Question & Answer" period then followed. Mr. Metzler and Mr. Feld answered a number of questions to the satisfaction of those proposing their problems. Due to the number and type of questions this portion was the "meat" of the evening's program and was highly educational.

There were 60 present at the banquet and 63 present at the technical session.

Birmingham

The May meeting of the Birmingham Section was held on the 3rd in Hooper's Cafe. This was a joint dinner meeting with the American Society for Metals. Approximately 95 members and guests heard Arthur N. Kugler, Mechanical Engineer of the Technical Sales Division of Air Reduction Sales Co., New York, give an interesting talk on "Welding Metallurgy." Included in Mr. Kugler's talk were uses for different types of electrodes, welding of stainless steels and aluminum.

A lively discussion followed the talk and the Section was fortunate in having a speaker of Mr. Kugler's experience to answer the many questions from the audience.

Boston

At the Annual Meeting of the Boston Section held on April 11th at the Graduate House, M.I.T., Cambridge, Mass., the following were elected as officers to serve for the year 1949–50.

Chairman—Philip N. Rugg, Boston Edison Co., Boston; *Vice-Chairman*—J. Donovan, Artisan Metal Products, Inc., Waltham; *Secretary-Treasurer*—Louis I. Dexter, The Tower Iron Works, Providence, R. I.; *Trustee*—H. J. Murphy, Mass. Engineering Co., N. Quincy; *Directors for two years*—P. J. Durney, Employers Liability Assurance Co.; H. S. Haywood, Welders Supply Co.; Elton J. Wiseman, Stone & Webster Eng. Co.

Technical speaker at this meeting was Clair Le Blanc of Wall Colmonoy Corp., who presented a clear-cut, interesting, nontechnical talk on "Spray Welding." A film on the same subject was shown in conjunction with the talk.

The March 14th meeting was also held at Graduate House, M.I.T. Dinner speaker was William C. White, President, E.S.N.E., who gave the news of the Engineering Society of New England. Technical speaker was Wm. G. Theisinger of Lukens Steel Co., whose subject was, "Manufacturing and Fabrication of Stainless Clad Steels." A film on the same subject was also shown.

The February 14th meeting was also held at the same place. F. L. Brandt, of the Thomson Electric Welder Co., presented the technical address on "Recent Developments in Synchromatic Flash Welding and Three-Phase Low-Frequency Converter Spot and Seam Welding."

The January 10th meeting was also held at the same place. E. H. Turnock, of Westinghouse Electric Corp., spoke on the subject, "Welding Electrode Coatings."

Chicago

A clear and forceful talk on fixtures for automatic welding was the highlight of the April 15th meeting of the Chicago Section. The speaker, H. J. Bichsel, Westinghouse Electric Corp., gave members and guests a short history of automatic welding developments as a preliminary to his principal topic. Bare wire, coated wire and submerged melt types of automatic welding were then explained by Mr. Bichsel, and their applications in modern industry cited. Almost all automatic welding setups are variations and combinations of circular or straight seams, he said.

Construction features of welding equipment and the fixtures for positioning various workpieces were described and discussed with the aid of slides. Perhaps most interesting in the slide presentation was a series showing welding installations in Westinghouse plants around the country for producing washing machines, fractional horsepower motor parts and other fabricated machinery.

William C. Pearson, 1st Vice-Chairman, presided over the meeting, which was called to order at 7:30 P.M. Two movies were shown before committee reports and the technical session. They were "Brazil's Fishing School" and "Devil Drivers," a film on auto racing.

The complete slate of officers and directors for the 1949–50 term, which was first announced by the Nomination Committee in March, was approved, as follows.

Chairman—William C. Pearson, Westinghouse Electric Corp.; *1st Vice-Chairman*—E. P. Auler, Taylor Forge and Pipe Works; *2nd Vice-Chairman*—A. F. Chouinard, National Cylinder Gas Co.; *Secretary-Treasurer*—L. C. Monroe, *Welder's Digest; Directors for 3-year-term*—C. B. Dewees, Dr. John M. Parks, Ray C. Bender and E. P. Gruca; *Directors for 2 years*—T. H. Swisher and L. A. Derrer and *Director for 1 year*—Maurice Sciaky.

Cleveland

Regular monthly meeting of the Cleveland Section was held on April 13th at the Cleveland Engineering Society. Coffee talker was H. Gefvert, Reliance Electric & Engineering Co. Mr. Gefvert presented many interesting pictures taken during his trip to Sweden last summer.

Technical speaker was Frederick H. Dill of the American Bridge Co. Mr. Dill spoke on the subject, "Structural Welding." Mr. Dill discussed specifications, designs and details of welded structures as well as testing of materials, welded joints and other structural processes.

There was an attendance of 200 at this meeting with 50 participating in the discussion.

As a result of a recent election, the following are the officers for the 1949–50 season of the Cleveland Section.

Chairman—C. T. Elder, The Cleveland Electric Illuminating Co.; 1st Vice-Chairman—J. Calvin Wyss, Reliance Electric & Eng. Co.; 2nd Vice-Chairman—John Austin, Republic Welding & Flame Cutting Co. and Secretary-Treasurer—J. F. Wagner, The Burdett Oxygen Co., Inc.

The Annual Welding Conference, or Symposium, held by the Cleveland Section, was held this year on May 13th at the Statler Hotel.

In addition to being unusually successful from both a technical and attendance standpoint, the Cleveland Section was honored to have the Board of Directors of the National Society present at some of the technical sessions and the evening dinner.

The Conference, as usual, consisted of an afternoon technical session featuring three papers, a dinner and an evening talk of a nontechnical nature.

Dusty Miller, editor, philosopher and humorist of Wilmington, Ohio, gave a down to earth, interesting, refreshing talk on "Attitudes" which was enjoyed by all.

The afternoon technical session featured three papers. The first, "The Relation of Heat Treatment to the Welding of Ferrous Metals" was presented by M. A. Scheil and J. J. Chyle of the A. O. Smith Corp. D. C. Holt, of Stacey-Dresser Engineering Co., presented a paper on "Auxiliar Heating in Welding Fabrication" and J. R. Henry, of Cleveland Diesel, spoke on "Welded Steel Bases for Diesel Generator Sets."

This year's Annual Welding Conference was dedicated to fellow-member J. F. Lincoln, President of The Lincoln Electric Co., who spoke briefly at dinner. As is the usual custom, the Annual Conference is dedicated each year to an outstanding member of the Cleveland welding fraternity whose pioneering and fine efforts have raised the standard of welding throughout the nation, or throughout the community.

Toastmaster for the occasion was the Section Chairman "Mike" Shane whose dry humor and Irish wit are well known throughout Northeastern Ohio.

General Chairman for the Symposium was John Austin, Welding Engineer for Republic Welding and Flame Cutting Co. Technical Chairman was Ross Yarrow of the same organization.

As usual, all the successful dinner arrangements were handled by stalwart and hardworking committeeman, Ed Scott of Scott-Tarbell Co.

Colorado

Very recently the Colorado Section held an educational welding clinic through the cooperation of the Denver Public Schools, the University of Colorado and The Linde Air Products Co. The clinic featured Heliarc welding which included the new HW-8 Spot Welder. The first night was devoted almost entirely to an explanation of the process and its possibilities. The second night gave those in attendance an opportunity to display their skill in welding various types of metal including Inconel, nickel, stainless steel, Everdur, brass, copper and aluminum.

The meeting was well attended with a total attendance of about 300.

Regular monthly meeting for April was held on the 12th in the Range View Room, Silver Wing Inn, Denver. Speaker at the technical session was Merrill S. Rosengren, Metallurgical Engineer, Stearns-Roger Mfg. Co., whose subject was, "Flame Hardening—Its Principle and Application." A very interesting meeting and a subject well presented. Due to the variation of ideas of proper flame hardening, this subject was well received. At the close of Mr. Rosengren's remarks the entire meeting were guests of the General Iron Works, who are manufacturers of the entirely automatic Denver Flame Hardener, where the machine was actually demonstrated.

Columbus

One hundred and fifty prominent engineers gathered together at the Fort Hayes Hotel on April 7th for the Columbus

Colorado Section Educational Welding Clinic

Section dinner meeting, a feature of the Tenth Annual Ohio Welding Conference sponsored by the Department of Welding Engineering of Ohio State University. At the speakers' table were representatives of the A.W.S. Sections in Youngstown, Cincinnati, Cleveland, Dayton, Toledo and Columbus.

Prof. Jacob B. Taylor, Vice-President and Business Manager of Ohio State University, welcomed Convention guests to the University, and gave a preview of plans for the future development of the University. Mr. Taylor outlined the long-range building program of the University and cited many fine current and future projects designed to increase the service of the University to the State.

Fred L. Plummer, District 4 Vice-President, announced that the Ohio State Student Branch of the A.W.S. had been recognized by the National Society as an active Chapter. The A.W.S. Student Branch which was inactive during the War was authorized to operate under its original charter which was granted in 1940. The O.S.U. group was the first student branch chartered by the A.W.S. Mr. Plummer introduced Paul R. Hill, Student Chairman, James M. Sellers, Walter A. Anderson, Jr., and Edward H. Harwart, newly elected officers of the student branch.

O. B. J. Fraser, 1st Vice-President of the A.W.S., the principal speaker of the evening, spoke on "The Future of Welding and the AMERICAN WELDING SOCIETY." Mr. Fraser is the Assistant Manager of the Development and Research Division of the International Nickel Co. and is located in New York City. Mr. Fraser joined the International Nickel in 1917 and has held a succession of increasingly responsible posts in that organization. Mr. Fraser is a member of many important national technical committees of the A.W.S., the American Society for Testing Materials, American Society for Metals, and many other organizations. Mr. Fraser is recognized internationally as an authority on the applications of nickel-alloy steels.

The increasing place of welding on the industrial scene was pointed out, and Mr. Fraser drew upon his wealth of experience, to illustrate the necessity for a unified attack on the problems associated with the welding industry. Mr. Fraser stated that in 1947 there was more than 306 million dollars spent in the United States on welding supplies and equipment alone and that the welding sales index showed more than twice the increase of the Federal Reserve Board index of Industrial Production between the period 1935–39 and 1947. Mr. Fraser described the benefits of a strong technical society in furthering the interests of manufacturers and users of welding equipment.

The last two meetings of the Columbus Section have been a tremendous success.

The Columbus Section cooperated with the Ohio State University in their Tenth Annual Welding Conference which was a real success. A meeting of all the chairmen of Ohio Sections as well as some University Officials was held to make plans for the Eleventh Annual Welding Conference. Dates and details will be released at a later date.

Dayton

The Eleventh Tri-Chapter all-day meeting, in conjunction with the American Society for Metals, was held on Wednesday, April 20th, at the Engineers Club of Dayton. Subject of this meeting was, "The Metallurgy of the Joining of Metals." Speakers included Gus Hoglund of the Aluminum Company of America, who spoke on "Brazing—Aluminum Brazing"; Roger J. Metzler, Development Engineer, Handy & Harman, who spoke on "Brazing—All Other Types." "Welding Rods" was the subject presented by E. H. Turnock of the Westinghouse Electric Corp. "Inert Arc Welding" was H. T. Herbst's subject of The Linde Air Products Co. "Arc Welding—Design, Fabrication and Construction" was LaMotte Grover's subject. Mr. Grover is connected with Air Reduction Sales Co. "Hard Facing" was G. E. Wilson's subject of Haynes Stellite Co; and John D. Gordon, Vice-President, and General Manager of Progressive Welder Co., spoke on "Design for Resistance Welding."

Detroit

A double-barrelled program featured the April 8th meeting in which Prof. E. Creutz, Cyclotron Project Administrator, Department of Physics, Carnegie Institute of Technology, presented a movie of the welding operations on Cyclotron coils at the Brooklyn Navy Yard, and Sterling S. Sanford, Heating, Ventilating and Air Conditioning Engineer, The Detroit Edison Co., presented the "Heat Pump," or heating and cooling with electric refrigeration.

Prof. Creutz' movie was both interesting and instructive and his comments added just the right touch in pointing out the unusual features which might otherwise have been missed in this unusual use of brazing and welding. The colored film showed the preparation of the special bus, and its subsequent brazing. In the 20-ft. diameter stainless-steel container, 10 welders operated simultaneously to equalize stresses. Views were also shown of the moving of the 120-ton precision machined steel forgings which go into the 1500-ton Cyclotron. The actual machining operations were also shown.

A little apart from welding was Sterling Sanford's talk on the "Heat Pump." This subject which has received national publicity recently was given a little rationalizing by Mr. Sanford. Using slides of graphs and charts to illustrate his talk, he told how the refrigeration cycle could be used to heat and cool and its physical and cost limitations, particularly in this section of the country.

No subject presented this year was received as well, if the discussion period which followed is the proper criterion.

Indiana

April 22nd dinner meeting was held at the Franklin Country Club, Franklin, Ind. R. T. Humphrey, General Manager, Mouldings, Inc., presented a problem to the Section of projection welding studs to a thin sheet of stainless steel to leave no marking. Several suggestions were given which Mr. Humphrey said he would try.

Technical speaker was Mr. Hadley, Engineer, Etna Machine Co., Toledo, Ohio. Mr. Hadley spoke on the subject of "Continuous Forming and Welding of Steel Tubing." A film on the same subject was shown in conjunction with the talk.

An inspection trip was made through the Franklin Plant of Noblett-Sparks. The plant was in operation on the muffler line with particular interest stressed on the welding operation.

Kansas City

The scheduled speaker for the February 24th meeting was unable to be present. A general code discussion by the Hartford and Ocean inspectors took place instead. As an added attraction a film on fishing and football was shown.

The March 10th meeting held at the Ad Club, had as its technical speaker, Patrick J. Patton, Regional Manager, Ransome Division, Worthington Pump and Machinery Co. Mr. Patton spoke on "Positioning for Welding."

Lehigh Valley

A. Amirikian of the Bureau of Yards and Docks, Navy Department, was the guest speaker at a joint meeting of the American Society of Civil Engineers and the Lehigh Valley Section of the A.W.S., which was held Monday, April 4th, at the Hotel Bethlehem, Bethlehem, Pa. C. L. Kreidler, Chairman, presided. One hundred members and guests attended.

Mr. Amirikian is the head Designing Engineer and Technical Consultant for the Bureau of Yards and Docks. He gave a very interesting illustrated talk on "Future Developments in Welded Steel Buildings."

Mr. Amirikian discussed the investigations made by the Bureau in the designing of welded structures. He told of the designs and new methods of fabrication developed by the Bureau which can be used to great advantage of buildings as well as floating structures.

A dinner meeting preceded the technical session, at which time, Guy F. Reinert, Boyertown, Pa., gave a talk on "Coverlets." Mr. Reinert showed colored slides of the Coverlets which he has found to exist throughout Pennsylvania.

The Lehigh Valley Section held its Annual Meeting and Ladies Night on Monday, May 2, at the Hotel Bethlehem.

C. L. Kreidler, Chairman, presided at the meeting. Harry W. Pierce, Assistant to the President of the New York Shipbuilding Corp., Camden, N. J., and 2nd Vice-President of the A.W.S., gave an interesting talk on a "Tour of the Japanese Empire." He told of the modes of living and the problems of transportation as he found them during a recent visit to Japan. The Section was pleased to have Dr. G. E. Claussen, Vice-President, A.W.S. District 2, attend the meeting. Refreshments and dancing followed with the members

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Do YOU Specify your welding requirements this way?

Do you know what the welding requirements are for bridges, buildings, piping, storage tanks, pressure vessels or whatever your type of fabrication?

This information, necessary for solving your practical, every-day welding problems, will be found in the standards issued by the American Welding Society.

Are You

—a Designer?

—a Welding Engineer?

—a Welding Operator?

—or engaged in any other capacity as a Purchasing Agent, Salesman or Administrative Executive?

Then you should know what the material, filler metal, design, workmanship, inspection and qualification requirements are for different products and structures. You should be familiar with the standard welding nomenclature and welding symbols used in everyday welding conversation and correspondence, in technical articles and in contract specifications and regulatory requirements.

If you are not already familiar with the codes, standards and specifications of the American Welding Society as well as the educational books, ask the Technical Representative (Liaison Officer) of your Local Section for a free copy of Bulletin 101 describing these publications. Also ask about the special discounts to members. If you prefer, write directly to AWS Headquarters.

It is easy to keep informed through American Welding Society technical publications.

They will help you.
Use them!

All sub-assemblies of this 6-story galvanized iron ventilator stack were positioned for welding and turned toward welder. The operator held electrode slightly off-center in direction of rotation.

Good Welds on galvanized metal are quick and easy with Ampco-Trode 10

Profit from the experience of a large southern producer of galvanized and light-metal fabrications. This company found it could do a better job on a six-story galvanized ventilator stack — saving both time and money — by welding with Ampco-Trode 10.

The stack was made of 11-gauge galvanized iron. Welding (in preference to riveting) saved time and metal weight. Using 1/8" Ampco-Trode 10 electrodes (in preference to steel) gave them four additional advantages:

1. Burn-off of the coating adjacent to the weld was held to a minimum. The weld deposit itself is rust-proof.
2. The braze-welded bond is as strong and ductile as the galvanized iron base-plate.
3. Undercutting and resulting weaknesses were eliminated.
4. No back-up strip was required. The low melting point of the weld metal gave penetration sufficient to produce a small, uniform inside bead for a sound weld.

Other Ampco bronze electrodes such as Phos-Trode and Sil-Trode can also give you simple, successful welds (smooth, free from pitting and porosity) on galvanized pipe, depending on your service requirements. Ask your Ampco distributor for his recommendations on your specific needs today.

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Lehigh Valley Annual Meeting and Ladies Night. Seated left to right: J. R. Fairhurst, H. W. Pierce, Q. E. Charlesworth. Standing: C. L. Kreidler, G. E. Claussen, Julius Naab.

and their ladies having a very enjoyable evening. The committee in charge of arrangements consisted of Q. E. Charlesworth, J. R. Fairhurst and L. P. Elly.

The following officers were installed for the 1949–50 season.

Chairman—Q. E. Charlesworth, Bethlehem Steel Co.; *Vice-Chairman*—J. R. Fairhurst, Ingersoll-Rand Co.; *Secretary-Treasurer*—Julius Naab, Ingersoll-Rand Co.; *Past Junior Chairman*—C.L. Kreidler, Lehigh Structural Steel Co.; and *installed as Directors for 3 years*—R. D. Stout, Lehigh University, and A. T. Bavaria, Lincoln Electric Co.

Los Angeles

The Los Angeles Section held its April meeting, Monday noon, April 11th, in the Galleria Room of the Biltmore Hotel. This meeting was also the opening day luncheon for the Western Metals Congress which was supported by a program of eighteen technical sessions and six panel discussions provided by the Los Angeles Section.

Welcoming address was made by Earl V. Grover, President, Los Angeles Chamber of Commerce. Mr. Grover is also President of a major local steel fabricating plant.

Toastmastership was brilliantly executed by Prof. Gilbert Schaller, Western District Vice-President, A.W.S. Two past national officers were present, L. W. Delhi, Past-President, and C. P. Sanders, past district Vice-President.

Joe Magrath, Executive Secretary, A.W.S., was the luncheon speaker. He discussed A.W.S. organizational activities at the national level. Disclosed also were plans for reorganization nationally and locally so as to provide development in the scope of activities and increase the membership of A.W.S. Particular emphasis was placed on the need for added participation of industry in A.W.S. Following this inspiring talk, meeting adjourned for participation in the five-day program of technical sessions.

Louisville

C. O. Hoglund, Welding Engineer, Aluminum Company of America, New Kensington, Pa., was the guest speaker at the April 26th meeting held at Preston Kunz Restaurant, Louisville, Ky. Mr. Hoglund spoke on "Present-Day Aluminum Welding" and discussed developments since he talked to the section on a similar subject four years ago.

Mr. Hoglund brought out the different problems in welding on heat-treatable alloys as compared with nonheat-treatable alloys. He gave facts and data on the welding of different thicknesses of aluminum and compared the relative economy of the electric arc method and the inert gas method. The advantages of brazing was explained for certain kinds of aluminum weldments. Lantern slides were used in connection with the talk and a variety of aluminum welded samples were on display.

After a discussion period the meeting was followed by a Dutch Lunch.

Michiana

The Michiana Section held its April meeting on the 21st at the Bendix Legion Hall, South Bend. The speaker was one of the Section's experts, A. B. White, Welding Engineer at the Clark Equipment Co., Buchanan, Mich. His subject was "The Arc Characteristics of Motor-Generator and Transformer-Type Arc Welders." The talk was a very informal discussion of the characteristics of both types of welders, which pointed out the basic reasons behind the behavior of these machines. In other words, good arc welders know what to do to make these machines produce the type of arc required, but this talk showed them why.

The talk was based on the voltage-ampere relationships in the circuits and showed how these were varied by changing settings on the machines. Mr. White illustrated his talk with chalk drawings which brought out the characteristics very satisfactorily.

An interesting film on "Fishing in Idaho" was also shown.

Milwaukee

The Milwaukee Section enjoyed an excellent talk by Anthony K. Pandjiris of the Pandjiris Weldment Co., St. Louis, Mo., at the April 22nd meeting held at the Ambassador Hotel. He devoted his time to a discussion of the necessity for cooperation between the design engineer, the shop welding foreman and the operators to obtain the maximum advantage from welding. A general outline of the proper approach to the design of a new weldment was discussed with emphasis on determining what loads and stresses are to be expected.

The necessity for stress relief under certain conditions was mentioned and the method of low-temperature stress relieving by heating with a torch was explained.

A movie of various types of fishing, ranging from wading streams in search of the elusive trout to deep sea fishing for tuna and martin, followed the buffet supper. Evidently the idea of a buffet style meal appealed strongly to the members, as nearly one hundred were present.

Nashville

The Nashville Section had the pleasure of hearing James F. Lincoln, President of The Lincoln Electric Co., speak at their April 27th meeting. He gave a very fine talk on the subject of "Habit and Its Effect on the Progress with the Human Race." In light of this, he discussed the problems with which arc welding has been confronted as to its general acceptance and development.

After his talk Mr. Lincoln was confronted with a variety of questions which he answered very capably. Everyone enjoyed his visit very much.

There was an attendance of about seventy including a great many visitors.

New Jersey

At the recent "Stump the Experts" program, held in the Engineering Societies Building, New York, April 13th, the New Jersey Section competed with the Bridgeport, Philadelphia and New York Sections. New York and New Jersey were tied for first place, whereupon the New York Section, acting as host of the

H-P-M's *NEW* TWO-WAY PRESS!

Straightening "A" frame weldments for TD-24 diesel tractors with a 200-ton H-P-M two-way press at International Harvester's Chicago Plant.

The Most Versatile Machine Ever Built For Straightening Weldments-

Everyone knows that material handling on straightening jobs is costly. When International Harvester found it necessary to straighten diesel tractor "A" frame weldments at several points, they asked H-P-M to design presses which would do the job without moving the part once it was positioned on the press bed. The answer was the new H-P-M two-way press which has cut straightening costs to the bone!

Here's how it works . . . . . press bed is stationary and the entire cylinder and ram assembly can be electrically traversed horizontally along the bed and also transversely between the pairs of strain rods. The result . . . . . straightening pressure can be applied at any point on the pressing area of the bed.

Do you have straightening operations where pressure must be applied at more than one point on the part? If so, this press will save you real money. Call in a nearby H-P-M engineer to explain its many time saving advantages. Write today.

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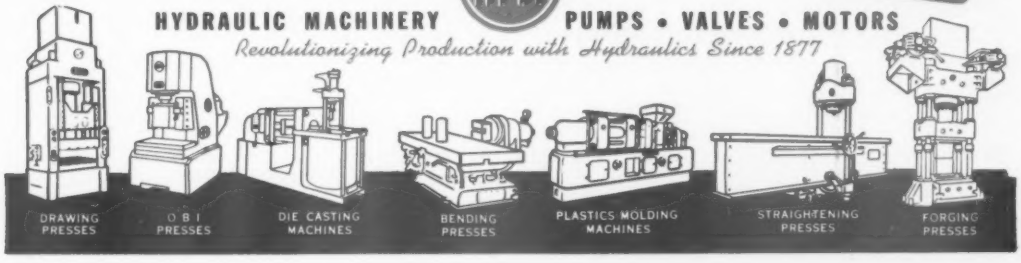

evening, conceded the contest to New Jersey.

At the regular monthly meeting for April held on the 19th at Essex House, Newark, N. J., O. R. Carpenter of the Babcock & Wilcox Co., Barberton, Ohio, spoke on the "Control and Inspection of Alloy Welding." This was a most informative talk describing the procedures involved in maintaining quality control of welded high-pressure equipment.

New York

After a futile attempt to break the tie with the team from the New Jersey Section, the New York Section as host conceded victory to New Jersey in the Battle of the Sections held on April 13th. The spirited competition from the other teams in the battle represented by Philadelphia and Bridgeport made the meeting one of the most interesting of the year. J. Lyell Wilson of the American Bureau of Shipping kept the meeting moving and all contestants happy in his role as moderator. Questions, both humorous and of a heckling nature, as well as comments from the audience to supplement the replies of the team members, made the meeting an informative one for all.

Judges for the battle were J. R. Skibo representing the Bridgeport Section; Harry W. Pierce, Vice-President District 2, representing the Philadelphia Section, and A. W. Steinberger representing the New Jersey Section. The Bridgeport team consisted of M. P. Bennett, J. R. Mitchell and L. F. Boch. The winning team was presented with a handsome leather portfolio suitably imprinted in gold for use by the Section Secretary.

New Jersey representatives were O. T. Barnett, K. H. Koopman and R. M. Wilson, Jr. Members of the Philadelphia team were O. C. Fredericks, Walter Mehl and A. J. Raymo. New York was represented by A. B. Kinzel, A. N. Kugler and E. Vom Steeg, Jr. The committee in charge of arrangements for the New York Section was G. L. Baker, W. L. Mitzenius, E. B. Stolle and S. T. Walter.

Niagara Frontier

The following officers and Executive Committee have been appointed for the year 1949–50.

Chairman—Ogden C. Mills, Mills Welding Supply Co., Inc., Buffalo; *1st Vice-Chairman*—Frederick V. Schilling, Westinghouse Electric Corp., Buffalo; *Secretary*—William J. Goodwin, Union Carbide & Carbon Res. Labs., Inc., Niagara Falls; *Treasurer*—Robert Siemer, Buffalo; *Chairman, Membership Committee*—Isadore Morrison, Morrison Steel Products Co., Buffalo; *Chairman, Program Committee*—E. Lyster Frost, Union Carbide and Carbon Res. Labs., Inc., Niagara Falls; *Executive Committee—1 year*—W. H. Swift, E. L. Frost, P. E. Gardner, O. C. Mills, W. J. Goodwin; *2 years*—F. Kovacsev, F. V. Schilling, Fitch Cady, II, E. M. Galbreath, F. J. Weiss; *3 years*—Peter H. Bos, G. Handyside, J. E. Summers. All past chairmen still living and active in Society are ex-officio members.

Approximately 80 members and guests were present for the final technical session of the season held at the Hotel Touraine, Buffalo, N. Y., on April 21st.

It was "Stump the Experts" night, with Clarence E. Jackson, Technical Committee Chairman, serving as moderator. B. Grimes, C. Freeman, C. H. Jennings, R. T. Breymeier, J. E. Ponkow and W. W. Webb served on the board of experts, and stood up well against a steady barrage of questions from the audience as well as from Mr. Jackson. The session was exemplary from most every standpoint, since members learned about the problems of their co-workers, secured knowledge of how similar problems were solved by others, and left the meeting in high spirits, ready to tackle most any welding problem which could come along.

The results of the annual election of officers and directors were announced at this meeting.

A team composed of C. H. Jennings, C. E. Jackson, A. R. Lytle and J. E. Ponkow, participated in the "Stump the Experts" night held at the May 2nd meeting of the Toronto Chapter, Canadian Welding Society. They competed with other teams composed of Canadian and British experts. Although they lost to the Canadian team by a very close margin, international friendships were cemented and the Section is looking forward to a visit from the Canadians in the future.

The March 17th meeting was held in conjunction with the Institute of Architects and the Society of Civil Engineers Chapters. Frederick H. Dill, Welding Engineer, American Bridge Company, Ambridge, Pa., spoke on "Structural Welding."

Northern New York

The March meeting was held on the 24th at the Danish Hall in Schenectady. Simon A. Greenberg, Technical Secretary of the A.W.S. and Editor of the *Welding Handbook*, was the principal speaker. The subject of his talk was "Advantages of Membership in the American Welding Society." The meeting was preceded by a dinner at Ferro's Restaurant which was attended by the Executive Committee, and all committee chairmen. A short business meeting was held immediately following the dinner, after which some of the problems of Section operation were discussed with Mr. Greenberg.

The April meeting was held on the 28th at the Stanley Club in Pittsfield, Mass. Roger W. Tuthill of the A.-C. Arc Welder Division of the General Electric Co., at Holyoke, Mass., was the principal speaker. The subject of his talk was "Inert Arc Welding." The meeting was well attended by a total of about 42 individuals, which included many from Schenectady and Troy.

Oklahoma City

Dinner meeting was held on Thursday, April 7th, at the Huckins Hotel, Oklahoma City. W. J. Poehlman of A. O. Smith Corp., Director of Spectrographic Research Laboratory, acquainted those of the welding field with the great commercial value of the spectrograph in controlling welding and weld materials. The necessity of these factors, as an inspection tool in the present great demand for increased production, and the simplicity of their procedures, were discussed. Mr. Poehlman's talk, complete with slides and movies, was extremely interesting.

Pascagoula

The April 6th meeting was held at the Pascagoula Country Club, Pascagoula, Mississippi. A. B. Tesman, Welding Engineer, North American Phillips Co., presented a practical talk on the application of the new Contact Electrodes. This is a new type of electrodes superheavily coated with mineral coatings for use semiautomatically or by manual torch welding, (dragged) in all positions. This results in more efficient higher speed welding of a higher quality than with standard electrodes. These have been in use in Europe for some time and are now being made in the United States.

Philadelphia

At the regular monthly meeting held on April 18th, the following officers were elected to serve for the following year.

Chairman—L. D. T. Berg, Areway Equipment Co.; *Vice-Chairman*—O. C. Fredericks, General Electric Co.; *Treasurer*—E. R. McClung, Jr., Lukens Steel Co.; *Secretary*—R. A. Guenzel, Southern Oxygen Co., Inc., and *Executive Committee*—Term expires 1952: R. D. Bradway, New York Shipbuilding Corp., J. S. Douglass, The Linde Air Products Co., J. R. Burg, Baldwin Locomotive Works. Term expires 1951. (Replace E. E. Goehringer, resigned) L. F. Kirkley, Air Reduction Sales Co.

At this meeting was presented a symposium on Stud Welding. Representatives of equipment manufacturers told three ways to do Stud Welding.

Graham Stud Welder was presented by L. D. T. Berg of Areway Equipment Co.; Nelson Stud Welder was presented by R. C. Singleton of Nelson Stud Welder Co. and Resistance Stud Welder was presented by James Cooper of Areway Equipment Co.

Each of the above methods of Stud Welding was outlined and presented by the speaker and was then thrown open to discussion from the floor.

The presentation of these methods at the same meeting helped to locate each process in the particular field in which it is most adaptable. The variety and range of work covered by stud welding made this a most interesting meeting.

Puget Sound

Forty-two members and guests of the Puget Sound Section met at the Benjamin Franklin Hotel in Seattle on April 25 for the regular monthly dinner meeting and to greet Joe Magrath, national Executive Secretary.

Mr. Magrath's report on the aims of the Society and his suggestions for Section betterment was enthusiastically re-

YOU CAN BE **SURE**.. IF IT'S

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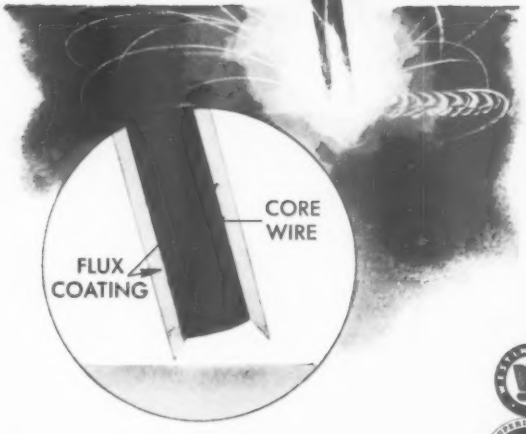
YOU CAN "DRAG" IT and weld with Hotter stubs



It's the new FP-2 electrode

Over 50 impartial tests have proved that the new FP-2 (6012) electrode . . . *gives better welds with hotter stubs . . . is better for "skip" and "drag" welding . . . gives a flatter bead . . . and has less undercut* than any electrode you have ever used. That's why it's a . . .

High-speed production tool . . . one you can burn with higher amps—until the stub is red-hot—and get good sound welds free of slag pits and gas pockets. And you can . . .

"Drag" it or "skip" it because the wire melts away faster than the heavy coating to form an inverted flux cup that's full of molten metal. What's more, the FP-2 is an . . .

All-position a-c—d-c electrode for easier, faster, better welding with all types of welding machines. Use it once and you'll be convinced.

For full details on the new FP-2, send for Page 29.1 (Catalog 26020). Westinghouse Electric Corporation, P. O. Box 868, Pittsburgh 30, Pa.

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EVERYTHING for Welding ANYTHING!

ceived and he was asked many pertinent questions at the close of his talk.

Messrs. Schaller, Crawford and Long reported on their visits to the Western Metal Congress.

Member Myron D. Stepath, Welding Supervisor, Puget Sound Naval Shipyard, gave his illustrated paper on Arc-Air Cutting and Gouging, which he had recently given at the Western Metal Congress. The paper proved very interesting and educational and brought out many questions and suggestions during the discussion period following the talk.

A total of forty-nine was present for the talks.

Rochester

The March meeting was held on the 21st at the University of Rochester.

Jack Sorensen, Superintendent of Vacuum Equipment Division, Distillation Products, Rochester, N. Y., spoke on "Welding Technique Used on Vacuum Equipment." He was assisted by Walt Statucki, Welding Supervisor of the Company.

Mr. Sorensen displayed some of the products of his company and explained how welding had overcome difficulties in construction, and made practical the use of metals where only glass had been used before.

The open discussion after his presentation testified to the interest shown in his subject, "Unfinished Business," a movie produced by United States Steel, was an added attraction.

The April 18 meeting was addressed by Clayton B. Herrick, Editor of *Industry and Welding* magazine. Mr. Herrick talked on maintenance welding in some of our larger industries such as packing, rubber brewing, drug and chemical. He explained the personnel, equipment, and procedures used by these companies in repairing and revamping the machines that keep production moving. Slides were used to illustrate his subject.

A sports and travel film was shown through the courtesy of Welding Supply Co., Rochester.

San Francisco

J. G. Magrath, Executive Secretary of the A.W.S., predicted a bright future for welding, before the April 18th meeting of the San Francisco Section, held at the Engineers Club.

Calling for "support of your Section, which is the unit of strength in the Society's battle against misrepresentation, procrastination and prejudice against welding," Mr. Magrath pointed out that as recently as 1910 "welding at its best was a good trick if you could do it." In 1929, he said, "welding became an art, and in 1926 an art and science." He predicted that soon the method of joining will stand established as a science.

Principal speaker at the dinner meeting was John J. Chyle, Director of Welding Research for the A. O. Smith Corp. Mr. Chyle discussed metal arc welding of alloy steels, stressing importance of proper heat treatment in achieving high-tensile strength. He emphasized necessity for test of procedure and operator qualifications in welding of hot-rolled, high-tensile steel, adding that details must be specified for uniform results. "Design, is a factor of considerable importance in fabrication of high-tensile steels," he said.

Toledo

The Toledo Section held its last regular technical meeting of the 1948–49 season on Wednesday, April 13th in the Commodore Perry Hotel.

Clayton B. Herrick, Editor of *Industry and Welding*, talked on "How Is Your Maintenance Welding?"

The speaker endowed with a very radiating personality is full of enthusiasm about things pertaining to welding. First he gave a short history of his magazine and in particular an explanation why the same issue uses three different covers in as many parts of the country.

His talk on maintenance welding was based on information gained on personal visits of many plants throughout the country. He found that a good many plants employ highly modern and specialized methods for maintenance repair by welding.

Slides which he used in his talk were extremely educational and told a clear story of the interest and importance given this method to keep plant machinery in good running order.

Western Massachusetts

On Tuesday, April 26, the Western Massachusetts Section held an organizational meeting to prepare for the coming year and to plan the final May meeting of the present year. Assistant Professor C. A. Keyser of the University of Massachusetts accepted the Chairmanship of the Program Committee for the next season. It was agreed to contact all members regarding their preference as to time and place of meeting, subject and entertainment. Frank Taft and James Flaherty were appointed to handle the executive membership drive.

The following officers and committee chairmen have been elected for 1949–50.

Chairman—R. W. Tuthill, General Electric Co.; *Secretary*—C. A. Keyser, University of Mass.; *Treasurer*—James W. Flaherty, Dyers Welding Equipment & Supply Co., and *Executive Committee*—Sidney Low, Theodore Morrisette, Rodolphe W. Gamache and Norman Randall.

Wichita

Merrill S. Rosengren, Metallurgical and Sales Engineer, Stearns-Roger Mfg. Co., Denver, Colo., was the speaker at the April 18th meeting. Mr. Rosengren spoke on the subject "Flame Hardening—Its Principles and Application." He is thoroughly familiar with his subject and presents it unusually well and is a very interesting speaker. Slides and a film "The Denver Flame Hardener" were shown in conjunction with the paper.

Worcester

Annual Meeting of the Worcester Section was held on April 27th at Svea Gille, Shrewsbury, Mass. Thomas Dowd, Traveling Secretary of the Boston Red Sox, gave a very interesting talk on baseball and showed a film of the 1948 World Series. A good time was had by all. Dinner consisted of Smörgasbord and free beer.

Employment Service Bulletin

Services Available

- A-578. Welding Engineer. B.S. in Met.E. Age 32. Last three years in sales, sales promotion, application, and development of welding electrodes. Considerable field sales work and numerous contacts among leading electrode users and makers. Written sales literature and technical articles for publication and given talks to A.W.S. chapter meetings. 10 years' experience in development and application of welding electrodes, welding and general metallurgy. Prefer sales or technical sales work.

Civil Service Examinations

The Board of U. S. Civil Service Examiners, U. S. Naval Training Center, Great Lakes, Ill., has issued an examining circular *No. EC-7-14-1*, describing positions available for Physical Science Administrators, Research Contract Administrators and Scientific Research Administrators. Salaries range from $5232 to $7432.

Research Contract Administrators plan, review, negotiate and administer research contracts between the Office of Naval Research and educational and other research institutions.

The Scientific Research Administrators plan, direct, appraise, coordinate and advise on the scientific work of individuals and laboratories conducting research under ONR contracts.

TENTATIVE PROGRAM

AMERICAN WELDING SOCIETY

30th Annual Meeting
week of October 17, 1949

CLEVELAND HOTEL, CLEVELAND, OHIO

Welding and cutting demonstration will be featured at the National Metal Exposition held during the week in the Cleveland Public Auditorium

TECHNICAL SESSIONS

All Technical Sessions will positively start on time.

No Stenotype Reporter—Members desiring to discuss papers are urgently requested to prepare discussion in writing in advance of the meeting and to send copies to Headquarters, as those preparing written discussion will be given preference at the session. Members and guests giving extemporaneous discussion at meeting should forward a written discussion as soon as possible after the meeting.

MONDAY MORNING, OCTOBER 17th
Three Simultaneous Sessions

STRUCTURAL DESIGN

Chairman—LaMOTTE GROVER
Air Reduction Sales Co.

Co-Chairman—F. L. PLUMMER
Hammond Iron Works

Design and Construction of a Modern Welded Deck Girder Highway Bridge
by NED L. ASHTON, State University of Iowa

Economical Design of Welded Buildings
by ROBERT E. ROBERTSON, JR., Saxe, Williar & Robertson, Engineers and Consultants

Proposed Design of Welded Rigid Frames for New York Subways
by MARTIN P. KORN, Consulting Engineer

A Strain Gage Test and Analysis of an Eighty-Foot H-Section Welded Truss
by A. WAIDELICH, The Austin Co.

PRESSURE VESSELS

Chairman—A. C. WEIGEL
Combustion Engineering-Superheater, Inc.

Co-Chairman—G. M. TREFTS
Farrar & Trefts, Inc.

Importance of Design in Construction of Tanks and Pressure Vessels
by WALTER SAMANS, Sun Oil Co.

Trends in Fabrication by Welding
by S. V. WILLIAMS, Struthers-Wells Corp.

Inert-Gas-Shielded Arc-Welding Aluminum Pressure Vessels
by A. J. HOPPER, Welding Engineers, Inc.

Notch Sensitivity of Mild Steel Plates
by A. B. BAGSAR, Sun Oil Co.

HARD FACING AND FLAME HARDENING

Chairman—R. P. TARBELL
Scott-Tarbell, Inc.

Co-Chairman—G. H. MEYER
The Linde Air Products Co.

Automatic Electric Hard Facing
by TURNER G. BRASHEAR, National Cylinder Gas Co.

Hot Hardness of Hard-Facing Alloys
by HOWARD S. AVERY, American Brake Shoe Co.

Hard-Facing Applications in the Steel Industry
by J. J. BARRY, Air Reduction Sales Co.

Flame Hardening of Large Diameter Rounds
by S. SMITH, Air Reduction Sales Co.

MONDAY AFTERNOON, OCTOBER 17th

Three Simultaneous Sessions

NONFERROUS METALS

Chairman—O. B. J. FRASER
The International Nickel Co.

Co-Chairman—F. G. FLOCKE
The Thornton Co.

Arc Welding of Molybdenum
by I. S. GOODMAN, Westinghouse Electric Corp.

The Welding of High-Nickel Alloys to Other Metals
by G. R. PEASE and H. B. BOTT, The International Nickel Co., Inc.

Seam Welding Monel Metal to Steel
by ERNEST F. NIPPES, ALLAN R. PFLUGER and GERALD M. SLAUGHTER, Rensselaer Polytechnic Institute

EDUCATION

Chairman—R. A. WYANT
Rensselaer Polytechnic Institute

Co-Chairman—GILBERT DOAN
Lehigh University

Welding in Engineering Education
by R. S. GREEN, The Ohio State University

Formal Training of Welding Personnel
by ALLEN C. TYLER, Acting Dean, LeTourneau Technical Institute

Continuation of Study of Welding and Welding Processes
by FRANK W. SCOTT, Marquette Mfg. Co., Inc.

RESEARCH

Chairman—ROSS YARROW
Republic Structural Iron Wks. Co.

Co-Chairman—L. K. STRINGHAM
The Lincoln Electric Co.

The Statistical Part in Welding Investigations
by B. B. DAY, Statistician, Director's Staff, U. S. Naval Engrg. Exp. Station

Brittle Failure and Size Effect in a Mild Steel
by K. J. STODDEN and E. P. KLIER, The Pennsylvania State College

Weld-Peening Investigations
by J. LYELL WILSON, American Bureau of Shipping

MONDAY EVENING

Chairman—GEORGE N. SIEGER, President
American Welding Society

Co-Chairman—M. S. SHANE, Chairman
Convention Committee

AWARDS OF PRIZES AND MEDALS

1949 ADAMS LECTURE

TUESDAY MORNING, OCTOBER 18th

Three Simultaneous Sessions

SYMPOSIUM ON SHIP STRUCTURE RESEARCH

Chairman—CAPT. C. M. TOOKE
Bureau of Ships, USN

Co-Chairman—
COMDR. R. D. SCHMIDTMAN
U. S. Coast Guard

Introduction
by REAR ADMIRAL ELLIS REED-HILL, U.S.C.G. Chairman, Ship Structure Committee

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by PROF. S. T. CARPENTER and CAPT. W. P. ROOP, U.S.N. (Ret.), Swarthmore College

Notched Bar Testing for Brittle Fracture
by DR. C. F. TIPPER, Cambridge University, England

Tests of Slotted Steel Plates
by E. M. MacCUTCHEON, C. L. PITTIGLIO, David Taylor Model Basin, U.S.N., and R. H. RARING, National Research Council

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Lowering Cost of Welded Construction
by OMER BLODGETT, The Lincoln Electric Co.

TUESDAY AFTERNOON, OCTOBER 18th

Three Simultaneous Sessions

SYMPOSIUM ON SHIP STRUCTURE RESEARCH

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The Committee on Ship Steel, National Research Council

Co-Chairman—J. LYELL WILSON
American Bureau of Shipping

Distribution of Relative Ductility in Steel Weldments
by L. J. KLINGLER and L. J. EBERT, Case Institute of Technology

A Study of the Various Bend and Tensile Specimens Used as Indices of Structural Performance and Weldability
by C. B. VOLDRICH and P. J. RIEPPEL, Battelle Memorial Institute

Effect of Cyclic Stresses on Impact Transition Curve of Ship Steels
by PROF. J. M. LESSELLS and H. E. JACQUES, Massachusetts Institute of Technology

Axial Tension Impact Tests of Structural Steels
by W. H. BRUCKNER and N. M. NEWMARK, University of Illinois

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Spot-Weld Consistency Studies
by JULIUS HEUSCHKEL, Westinghouse Research Labs.

Spot Welding Heavy Gage Structural Steel
by ERNEST F. NIPPES and R. F. UNDERHILL, JR., Rensselaer Polytechnic Institute

Slope Control and Its Effect on Spot and Projection Welding
by I. W. JOHNSON, General Electric Co.

MISCELLANEOUS

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Carnegie-Illinois Steel Corp.

Co-Chairman—J. J. CHYLE
A. O. Smith Corp.

Welding of Zinc-Base Die Castings
by ROLAND H. OGDEN, Alladin Rod & Flux Mfg. Co.

Brazing of Stainless Steel
by C. H. CHATFIELD and A. W. SWIFT, Handy & Harman

Magnaflux Inspection of Welded Storage Tanks
by F. A. UPSON, Standard Oil Company (Indiana)

WEDNESDAY MORNING, OCTOBER 19th

Three Simultaneous Sessions

APPARATUS

Chairman—H. O. HILL
Bethlehem Steel Co.

Co-Chairman—A. M. SETAPEN
Handy & Harman

Design Features of a Welding Generator with Controlled Reactance
by E. E. TISZA and J. M. TYRNER, Air Reduction Sales Co., and O. KOBEL, G. D. Peters & Co. of Canada, Ltd.

Measurement of Flux Densities in Steels for Magnetic Particle Inspection
by T. E. HAMILL, Naval Gun Factory

Economical Arc Welding
by S. OESTREICHER, Harnischfeger Corp.

RESISTANCE WELDING

Chairman—WILSON SCOTT
Westinghouse Electric Corp.

Co-Chairman—B. L. WISE
National Electric Welding Mach. Co.

Fatigue Tests of Spot-Welded Mild Steel and Stainless Steel Sheets
by PROF. GEORGES WELTER, École Polytechnique, Montreal, Canada

Spot Welding Galvanized Steel
by M. L. BEGEMAN, M. L. HIPPLE and L. CULLUM, JR., The University of Texas

The Increase in Electrical Resistance Caused by Nonuniform Current Flow Through a Specimen
by DEAN W. B. KOUWENHOVEN, School of Engineering, The Johns Hopkins University

Design and Application of Portable Resistance Welding Tools
by C. H. DAVIS, Jr., The Budd Co.

ALUMINUM

Chairman—G. O. HOGLUND
Aluminum Co. of America

Co-Chairman—DR. DANA SMITH
Permanente Metals Co.

The Economy of Shielded Arc Welding of Aluminum
by FRITZ ALBRECHT, Glenn L. Martin Co.

Fusion Welding 61S Aluminum Alloy
by K. E. MERKLIN, and M. J. STERN, Boeing Airplane Co.

Shear Strength Consistency of Spot Welds in Alclad 24 S-T3
by J. C. BARRETT, Glenn L. Martin Co.

Heliarc Welding of Aluminum Alloys
by F. H. STEVENSON, Modern Metal Spinning & Mfg. Co.

WEDNESDAY AFTERNOON, OCTOBER 19th

BUSINESS MEETING

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The new General Electric three-phase frequency changer welding control has definite advantages for many users of resistance welders. Below are some of the questions we are frequently asked about it.

Q. I'm planning to install more machines, and my distribution lines are heavily loaded. Should I consider three-phase control?

A. Yes, because it has low kva demand, plus many other advantages. However, it may be more economical to solve your power supply problem another way—we'll be glad to help you.

Q. Can three-phase control be used for different types of welding?

A. It is used for spot, seam, projection, and gun welders, although we do not generally recommend it for the latter because it is usually economically unjustified.

Q. Where is it particularly useful?

A. In welding aluminum. There is little tip pick up and consequently not much electrode cleaning required with three-phase control.

Q. What is the difference between this system and the conventional single-phase system?

A. Basically, the method of producing a weld is the same in both. However, by converting three-phase to single-phase, low-frequency power, there is less reactance and lower kva demand. The bulletin gives more details. Now let's check the advantages shown at right.

Have you seen

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General Electric's MORE POWER TO AMERICA full-color movie? Clearly describes and explains various types of welding—contains tips for improving production with this process. Ask your welding distributor or the nearest G-E office for a showing.

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phase control

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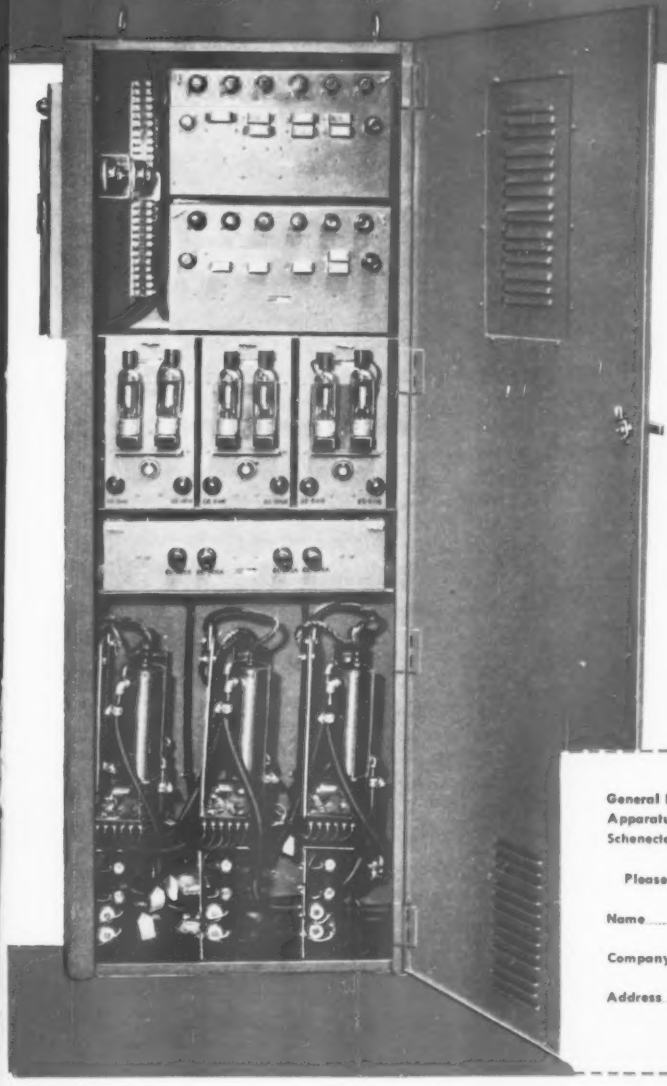

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4. only one, compact cabinet, machine mounted
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THURSDAY MORNING, OCTOBER 20th

Three Simultaneous Sessions

ARCS AND ELECTRODES

Chairman—J. H. HUMBERSTONE
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Co-Chairman—O. T. BARNETT
Metal & Thermit Corp.

A Sensitive Relay Instrument for Analyzing Welding Arc Short Circuits Caused by Metal Transfer
by R. C. McMASTER, D. C. MARTIN and A. LEATHERMAN, Battelle Memorial Institute

Heat Effects in Anode Spots of High-Current Arcs
by DR. T. BENJAMIN JONES, Johns Hopkins University

Application of Mild Steel Welding Electrodes
by F. R. STRATE, Air Reduction Sales Co., and R. I. STROUGH, Arcrods Corp.

Energy Distribution in Electric Welding
by CLARENCE E. JACKSON and A. E. SHRUBSALL, Union Carbide & Carbon Res. Labs.

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Chairman—ROY F. JOHNSON
Pullman-Standard Car Mfg. Co.

Co-Chairman—A. G. OEHLER
Editor, Railway Mechanical Engineer

Evolution of the Welded Freight Car
by L. E. GRANT, Chicago, Milwaukee, St. Paul & Pacific Railroad Co.

Pressure-Welded Rail
by L. ADAMS, Oxweld Railroad Service Co.

Arc Welding in Railroad Shops
by E. DiLIBERTI, Air Reduction Sales Co.

Car Rehabilitation
by H. E. GANNETT, Chicago, Burlington & Quincy Railroad

WELDABILITY

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Union Carbide & Carbon Res. Labs.

Co-Chairman—R. E. SOMERS
Bethlehem Steel Co.

Strain Aging in Welding Low-Carbon Structural Steel
by W. H. BRUCKNER and S. W. SANDBERG, University of Illinois

The High-Frequency Notch Bend Test
by BELA RONAY, U. S. Naval Engrg. Exp. Station

Studies Concerning the Strain-Aging of Arc Welds in Mild Steel
by A. E. FLANIGAN, University of California, Los Angeles

Weldability of Corrosion and Heat-Resistant Alloys
by M. J. STERN and W. L. SLOSSON, Boeing Airplane Co.

FRIDAY MORNING, OCTOBER 21st

Three Simultaneous Sessions

INSERT GAS WELDING

Chairman—C. B. VOLDRICH
Battelle Memorial Institute

Co-Chairman—C. A. LOOMIS
Bureau of Ships, USN.

Heliarc Welding in the Automotive Industry
by F. J. PILIA and R. H. BENNEWITZ, The Linde Air Products Co.

Aircomatic Welding
by E. H. ROPER, A. MULLER and G. GIBSON, Air Reduction Sales Co.

Automatic Heliweld Applications
by H. O. JONES, Air Reduction Sales Co.

Applications for Helium in Inert Arc Welding
by M. J. CONWAY, General Electric Co.

STAINLESS STEEL

Chairman—WENDELL F. HESS
Rensselaer Polytechnic Institute

Co-Chairman—E. VOM STEEG
General Electric Co.

Corrosion Resistance of Molybdenum Bearing Stainless Steel Weld Metals
by R. D. THOMAS, JR., and ANTON L. SCHAEFFLER, Arcos Corp.

Problems Associated with the Welding of Stainless Clad Steel
by PERRY C. ARNOLD, Chicago Bridge & Iron Co.

Resistance Welding of Stainless Steel Trailer Components
by BYRON GATES, The Budd Co.

Stainless Steel Fabrication by Inert-Gas-Shielded Arc Welding
by CHARLES D. BONIFIELD, The Globe Co.

GAS CUTTING

Chairman—J. J. CROWE
Air Reduction Sales Co.

Co-Chairman—
H. E. ROCKEFELLER
The Linde Air Production Co.

New Developments in Oxyacetylene Cutting Machines
by W. BEGEROW and A. H. YOCH, Air Reduction Sales Co.

Steel Warehouse Shape Cutting with Electronic Tracers
by KEITH J. EVANS, Joseph T. Ryerson & Sons

Flame Cutting
by JAMES T. LEWIS, Lewis Welding & Engineering Corp.

Powder Cutting and Scarfing Process
by C. W. POWELL, Republic Steel Corp.

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Supplement to The Welding Journal, June, 1949

Fatigue of Welded and Riveted Trusses

Welded trusses, if made with due consideration to design, materials and workmanship, are equal to riveted trusses in fatigue and superior to riveted trusses in static tests

by Dr. C. Cerardini

CAREFULLY built riveted trusses designed with a factor of safety in fatigue of $V_r = 1.5$ have sufficient strength under repeated loads. This statement is amply supported by the good behavior of riveted structures of many types subjected to fatigue over several decades.

In welded construction, which has developed only since about 1935, trusses have not yet been designed with sufficient fatigue strength. Their weak point is generally at the junction of the truss members at the gussets. Thus in 1934 and 1935 when this laboratory made fatigue tests on a welded truss, the fatigue strength was found[1] to be about 14,200 psi. (zero to maximum tension.)

Since then, there has been considerable progress in welded design particularly in discarding ideas inherited from riveting.[2] Progress in Switzerland from 1935 to 1944 in welded trusses has been shown by tests made at this laboratory on three test trusses in 1944 to 1946. By way of comparison tests (static and fatigue) also were made on two riveted trusses.

THE TEST TRUSSES

The design of Trusses I and II, which differed only in a few details, and of Truss III is shown in Fig. 1. The following principles governed the construction of these trusses.

(*a*) The members of the truss consist of flat strips assembled by fillet welds.

(*b*) The members are butt welded to the gusset plates machined so as to avoid notches in the transition zone and on the surface of the welds.

(*c*) The cross section of the members of the truss and the shape of the gussets have been selected to provide continuous transmission of stress and to avoid stress concentrations.

(*d*) The cross section of the members and gussets has been made as extended as possible to minimize secondary stresses resulting from the rigidity of the assembly.

(*e*) During construction every precaution was observed to secure a first-class welded structure.

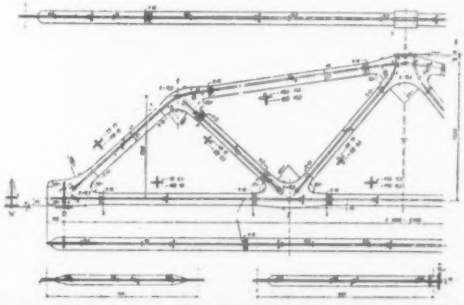

Fig. 1 Welded trusses Nos. I to III. Dimensions in millimeters. Span, 19 ft. 8 in.

Translation of "LaRésistance à l'Endurance des poutres à treillis soudées et rivées" published in *Journal de la Soudure*, **38**, 199–203, 228–231 (1948).

The author is scientific aide at the Federal Testing Laboratories, Zurich, Switzerland. (Translated by Dr. G. E. Claussen, Chief Metallurgist, Reid-Avery Co. Baltimore, Md.)

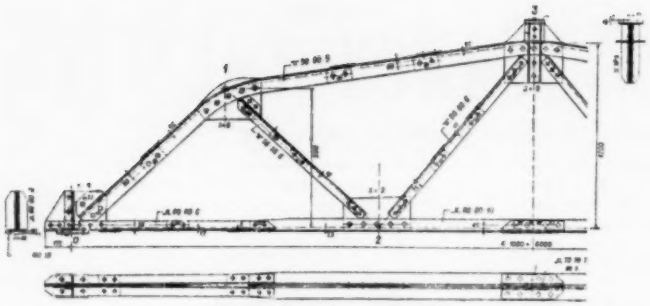

Fig. 2 Riveted truss No. IV

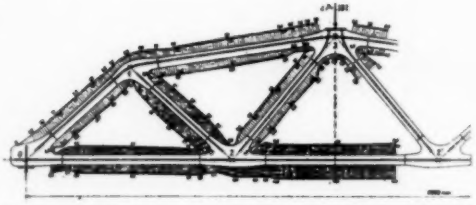

Fig. 3 Distribution of stresses (Kg./mm.²) in the loaded trusses

Type A trusses had cross-shaped members, while Type B had T- and I-shaped members. Riveted Truss IV was similar in all respects to welded Trusses I and II. The members consisted of two angles back-to-back placed symmetrically with respect to the plan of the truss, Fig. 2. The second riveted truss was the same one used by Prof. Th. Wyss in 1920–21 to determine strains under static loads, particularly near the gussets. For this reason the gussets were rather large and the members were not extended to any extent.

All trusses were built with the aid of processes currently employed in structural fabricating shops. First-class workmanship was required.

THE TESTS

Every truss was subjected to static and fatigue tests very carefully in the large transverse bend testing machine of this laboratory. In static tests the following measurements were made:

(*a*) Vertical and horizontal displacements of the junctions using a Stoppani gage.

(*b*) Rotations and deformations of the gussets using Stoppani and Huggenberger clinometers.

(*c*) Stress distribution in the members using Huggenberger tensometers in order to determine the loads in the members, the stresses at the center of gravity, and the stresses along the edges, or the principal loads and secondary moments, Fig. 3.

(*d*) The stress distribution in the most interesting gussets, Fig. 4.

(*e*) The zones of plastic deformation, using a special lacquer.

The results of these measurements have been compared with calculated values. Truss I also was subjected to a load test in the plastic region and to a buckling test.

Fatigue tests were made with the aid of two special Amsler pistons, Fig. 5, actuated by two Amsler pulsators

Fig. 5 Fatigue test of a welded truss

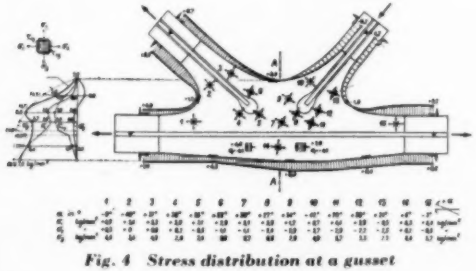

Fig. 4 Stress distribution at a gusset

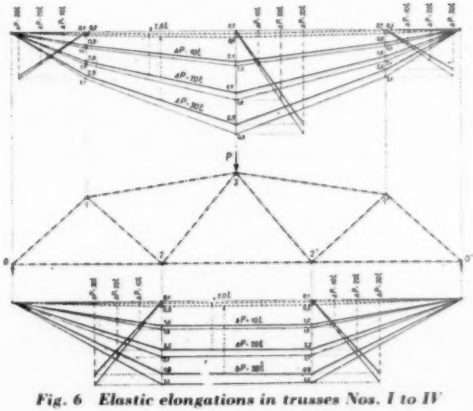

Fig. 6 Elastic elongations in trusses Nos. I to IV

coupled together. The frequency of pulsations was 250 cycles per minute. About one million pulsations was applied at each of several gradually increasing loads. After each fatigue fracture the trusses were repaired. Thus each truss underwent several fatigue tests. These tests permitted us to determine the fatigue strength of each truss for one million cycles; using the cross section of the members in calculating the stress. For the riveted truss the net section was used in calculating the stress.

RESULTS OF STATIC TESTS

Under a load equal to 1.5 times the maximum permissible load the welded trusses and riveted Truss IV behaved in a completely elastic manner. There was perfect proportionality between stress and strain Fig. 6. All trusses underwent small permanent deformations under the first load. The special lacquer permits us to state that for the riveted truss these permanent deformations are due to slip along faying surfaces in the riveted joints, while in the welded trusses they are due to local plastic deformation resulting from release of shrinkage stresses created by welding. These permanent strains averaged twice as large for the riveted truss as for the welded trusses. The following results were obtained for welded Truss No. I.

(*a*) Proportional Limit with respect to the average stress in member 2-2′ = about 34,000 psi.

(*b*) Proportional Limit with respect to the edge stress in the same member = about 38,500 psi.

Yield Point with respect to the average stress in member 2-2′ = about 41,000 psi.

Yield Point of steel from which the trusses were built = about 44,000 psi.

Plastic phenomena were studied by means of the brittle lacquer. The results of measurements of rotation of each gusset at several points are shown in Fig. 7.

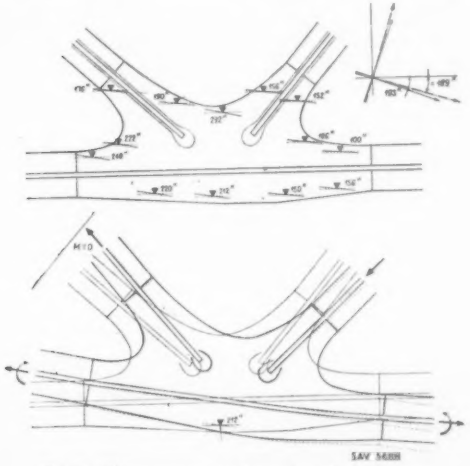

Fig. 7 Measurements of rotation of the gussets

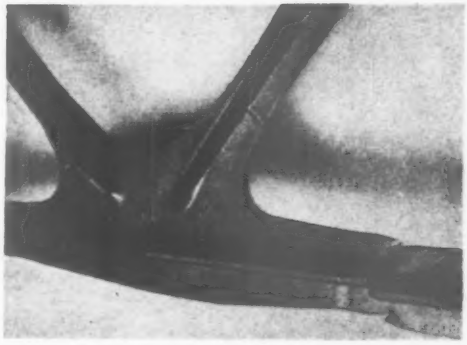

Fig. 8 View of a gusset of trusses I and II

The gussets underwent more deformation in the riveted Truss IV than in the welded Trusses I, II and III. In general the rotation measurements agreed with calculations, as did the stress measurements, Fig. 3. Likewise the secondary stresses due to riveting the members to the gussets agreed with calculations. Certain irregularities revealed by the measurements in the diagrams of secondary strains may be attributed to the following factors:

(*a*) For the welded trusses, to the deformations due to shrinkage, which caused lateral twisting of the members.

(*b*) For the riveted trusses, to the fact that a riveted structure is not entirely rigid, that is not completely monolithic.

These irregularities were magnified by the small scale of the test trusses but have practically no effect on the strength of the trusses. The results of the study of stress distribution in and near the gussets lead to the following conclusions.

For the welded trusses of Type A, Nos. I and II, the transfer of stress from one element to another is continuous and uniform, thanks to the appropriate selec-

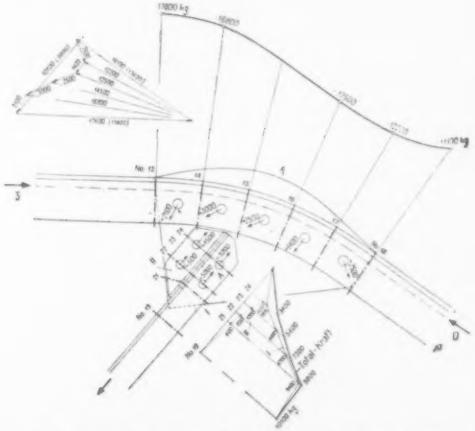

Fig. 9 Distribution of stresses in the riveted truss

Table 1—Results of Fatigue Tests

Truss	Designation of fatigue fracture	Cause of failure	Fatigue limit, psi.*	Average value of fatigue limit, psi.	Over-all average fatigue limit of welded trusses, psi.
No. I Welded	A	Porosity in the longitudinal fillet welds in the bars at the transition of the fillet weld to the butt weld	20,000	22,000	23,200
	B		22,000		
	C		22,700		
	D		23,400		
No. II Welded	A	Butt weld, weld contained no defects	24,100 (27,000)	24,800	
	B	Longitudinal fillet weld; weld contained no defects	24,800		
	C	Butt weld; weld contained no defects	24,800		
No. III Welded	A	Weld joining member 2–2′ to the gusset 2–2′. Stress concentration	22,700	22,700	
	B		22,000		
	C		24,100		
	D		22,700		
No. IV Riveted	A	Cover plate in member 2–2′	20,700	19,200 with respect to net section	
	B	Junction of member 1–2 to gusset 1 (corner)	22,700		
	C	Gusset 2—junction with member 1–2	23,400		
	D_1	Gusset 2′—junction with member 1′–2′	23,400		
	D_2	Cover plate in member 2–2′	20,700		
"Wyss" Riveted	A	Diagonal 1–2, junction with gusset 1	16,300	18,500 with respect to net section	
	B	Gusset 4, junction with diagonal 1–4	17,700		
	C	Diagonal 1–2, junction with gusset 1	17,000		
	D	Post 1′–2′. Deep notches at edge, due to influence of secondary stresses	17,000		
	E_1	Tension member 2–4 in the free portion	21,300		
	E_2	Gusset 1, junction with diagonal 1–4	20,700		

* Fatigue limit expressed as tension range from zero to maximum tensile stress.

tion of cross section of the members and of the shape of the gussets, Fig. 8. The stress distribution in the gussets of the welded Type B, truss No. III is very like that in trusses I and II. However, where the wings of the T and I curve inward, there is a stress concentration due to the transfer of stress from the wings of the members to the gusset plate. From this point of view the cross-shaped members of Type A are preferable to the T- and I-shaped members of Type B. As for the continuity and regularity of transfer of load from members to gussets the riveted truss is slightly inferior to the welded truss, Fig. 9. The transfer of stress in the riveted joint occurs partly by friction and partly through the rivets in shear. Very high stresses occur around the rivet holes, which cannot be calculated theoretically. In each of the riveted assemblies the section at which the first row of rivets is found is most highly stressed, because at this point the load in the member acts at full strength. This is a well-known fact and is confirmed by these tests. The stresses acting on the members tend to concentrate in front of the first row of rivets in that portion of the member immediately adjacent to the gusset. As a result the stress is not uniformly distributed and the first row of rivets is most heavily stressed.

The buckling test on Truss I showed that the critical load for the compression members was higher than that calculated according to this laboratory's theory for eccentric loads on the assumption of an initial eccentricity expressed by the formula

$$m = \frac{P}{K} = \frac{0.5L}{110} \qquad (1)$$

where

P = eccentricity of load
K = radius of gyration
L = degree of slenderness

In view of the irregularity of the axis of the members which had been observed during test and which was due to shrinkage during welding, it was reasonable to assume an initial eccentricity of load.

FATIGUE TESTS

The fatigue tests, Table 1, showed a 5% superiority of the welded trusses Nos. 1 to 3 over the riveted Truss No. 4. The fatigue failures in Truss I were caused by the transition from a fillet weld to a K-type weld. On the other hand, in Truss II failure was due to stress concentration at gussets 2 and 2′. Truss III attained practically the optimum value of fatigue limit: namely, 25,600 psi. The Wyss truss, which was built a long while ago for purposes different from this test, had a rather low fatigue value. For trusses I to IV, which had thin members, the secondary stresses due to rigidity at the connections and shrinkage stresses had practically no effect on fatigue strength. On the contrary, defects resulting from poor design and concentration of stress at connections were very important in welded

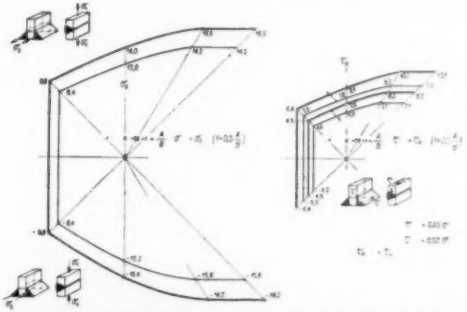

Fig. 10 Permissible stresses for trusses in steel AcN welded without defects. Stress in Kg./mm.²

Truss II and the riveted trusses. All in all, we may consider the results of the fatigue tests very satisfactory since the experimental trusses were much more severely stressed than in service.

CONCLUSIONS

The tests show that welded trusses are perfectly equivalent to riveted trusses if the following essential rules are observed during fabrication. These rules relate to (*a*) the materials of construction, (*b*) the design of the truss as a whole and its details and (*c*) the method of fabrication. The permissible design stresses for welded trusses of first-class structural steel AcN are shown in Fig. 10. The compression members are designed on the same basis as for riveted trusses. Eccentricity of load is inevitable, owing to shrinkage distortion during welding. Formula (1) should be used. The following safety factors apply with respect to:

Yield	$\geqq$	2.0
Fatigue	$\geqq$	1.5
Buckling	$\geqq$	2.0 taking account of initial eccentricity of load

The following rules must be observed in fabricating first-class welded trusses. The structural steel AcN must meet federal specifications. First-class covered electrodes must be used of a grade corresponding with the strength of the steel. Weld metal and welds must fulfill the requirements of this laboratory.

Members should be composed, if possible, of flat plates assembled by continuous longitudinal fillet welds. Rolled sections should be avoided. The cross is the fundamental shape from which more complex shapes should be derived. Complicated sections, such as box sections, should be avoided if they are difficult to weld.

The results of these tests are useful in designing railway bridges with a span of 115 to 130 ft.

As far as possible the longitudinal fillet welds in the members should be symmetrical with the axis of the member and at a good distance from the edges of the section. In exceptional cases the fillet welds may be replaced by K welds. For a given joint it is good practice to avoid passing from a fillet to a K weld, for these changes of shape give rise to stress concentrations which lower the fatigue strength. The longitudinal fillets must be continuous and uninterrupted for the whole length of the member. At the free ends a special transition, Fig. 11, should be used. Tests[3] prove that these transitions have high fatigue value. As for changes in section from member to member, they should be accomplished by varying the thickness and width of the flat bars. These changes in section should be made gradual and continuous so as to avoid notches and acute angles.

To reduce secondary stresses to a minimum the axes

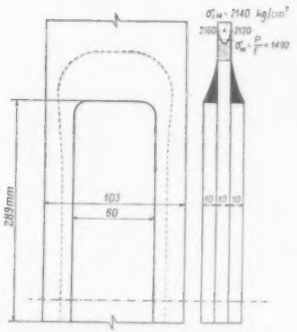

Fig. 11 Favorable design of fillet welds. Dimensions in millimeters

of the members should meet on center and the cross section of the members should be as slim as possible. Members should be butt welded to the gussets, and the gussets themselves should be so shaped that loads can be transmitted in a continuous fashion without stress peaks. Butt welds in tension, as well as the ends of the longitudinal fillet welds on the members, should be carefully machined or ground.

The greatest importance must be attached to the execution of the welding. Defective workmanship is more serious in welded construction than in riveted. Careless workmanship may have grave consequences especially in structures subject to fatigue. Inspectors must follow the welders closely. Distortion and shrinkage stresses should be held to a minimum by judicious sequence of welding. Preheating is beneficial particularly when the ambient temperature is low.

The structure to be welded should be placed in the most favorable position for welding. If positioning is impossible an attempt should be made to locate important welds in positions easy to weld. Parts containing welds that are not completely perfect should be reinforced and the permissible stress used in design should be reduced by about 20%.

Any welded trusses built according to these prescriptions are equivalent to riveted trusses from the fatigue standpoint. The welded trusses are superior from the standpoint of static loads. During the period 1935 to 1944, Swiss specifications have raised permissible stresses for welded structures 40%.

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This Thing Called Weldability

Present knowledge of weldability is critically reviewed and set forth in clear, understandable language. The article forms a basis for future research and development. It suggests methods of improved application of present test procedures relating to weldability

FOREWORD

THE Weldability Committee of the Welding Research Council was organized in 1941. They have had cognizance of a number of research programs pertaining to the general field of weldability. This report is an attempt to treat our present knowledge of weldability in the most critical manner. It is felt that this presentation is necessary as a basis for future research, further technical development and improved application of present test procedures relating to weldability. It is also true that the question of weldability is not ready for final discussion because of the numerous unsolved problems. However, there is need for clarification and unification of the information which is now available. The Welding Research Council has maintained a committee—a large committee—whose personnel have had a greater variety of interests in welding. Members have been interested from many angles, such as materials, design, fabrication and process application. Engineers of a great variety have been members of this committee. From training and employment their interest has been metallurgical, mechanical, electrical, chemical or structural, in fact, their interest lies in all fields of engineering. Such a heterogeneity of interest has been particularly stimulating.

I. WHO IS INTERESTED IN WELDABILITY?

In considering the general problem of weldability, we might ask who is interested in weldability, for whom are we trying to develop a method of evaluation of the weldability of metal: is it for the welder in the weld shop, the shop management, the metallurgical laboratory, the designing engineer, the materials engineer or the welding engineer? It appears that we should be aiming this development primarily for the benefit of the materials and welding engineers in order to secure maximum economy in fabrication and maximum serviceability of weldments. Weldability should be considered from an engineering standpoint, with full recognition of the importance of metallurgical and other factors which may be involved in this evaluation. We are interested in weldability because we want to have a better understanding of the problem of welding a given material by a given process to produce a given design for a given service.

II. WHAT IS WELDABILITY?

It is generally accepted as axiomatic that all steels are weldable. Therefore, any definition of weldability is meaningless unless it incorporates the idea of degree of weldability. The degree of weldability should incorporate the ease or facility with which a desired weld can be obtained. For example, it is often considered that a perfect weld is one in which two pieces of steel are joined by fusion into a continuous member which is equal in every respect to a similar piece of steel containing no welds. However, even though this was achieved with several steels, they still might not all be considered as equally weldable since it might be more difficult to achieve the perfect joint with one steel than with another. On the other hand, the ease of welding all steels might be considered to be the same, provided that the method and technique of welding are adequate for fabricating a structure that is satisfactory for the purpose intended.

In an actual definition of weldability, one is confronted with the inadequacy of a single definition to describe the term satisfactorily for the several viewpoints which are encountered. Seferian and Leroy in their discussion of weldability divide the field into three parts: (*a*) Constructional weldability, which depends on base metal, filler metal, operator's skill and rigidity and mass of the construction. Tests for constructional weldability involve shrinkage stresses, such as the rigid-clamp and bead-bend tests. (*b*) Operative weldability, which depends on base metal, filler metal and operator's skill. Tests involve the heat-affected zone, all-weld metal and base metal. (*c*) Metallurgical weldability, which depends on the intrinsic properties of base metal, and is not affected appreciably by the quality of the filler metal or by the operator's skill.

This paper was originally prepared by C. E. Jackson, Chairman of the W.R.C. Weldability Committee, and connected with the Union Carbide & Carbon Res. Labs., Inc., and modified by members of the Weldability Committee. It constitutes a report of the Weldability Committee.

Tests for metallurgical weldability include the usual tension, bend, shear and hardness tests for welds. It has been felt for some time by American investigators that any complete definition of weldability must be related to performance or service requirements.

A complete definition of any term is difficult; for example, cast iron or steel is still almost impossible to define. There are books written to describe steel and usually the authors modestly admit that the discussion is incomplete. For the purpose of this summary, however, it is felt that there should be some statement that can be pointed to as a definition of weldability which in a broad sense will concur with the general thinking about the subject. It will then be simpler to cope with the equally complicated and more pertinent problem of evaluating weldability.

With full recognition of the difficulties involved in defining weldability, the following definitions may be suggested:

1. For the purpose of procurement: Weldability is defined as that combination of properties which control the suitability of a metal to be joined by welding under specified conditions to form a continuous member.

2. For constructional purposes: Weldability is defined as that combination of properties which control the practicability of joining a metal by welding under a set of imposed conditions to form a joint having properties adquate for the purpose intended.

3. From metallurgical considerations: Weldability is defined as that combination of properties which control the facility with which a metal may be fabricated by welding, under a set of prescribed conditions, without undue detrimental effects on the physical properties of that metal.

The American Welding Society Definitions Committee has recently defined weldability. This proposed definition reads: "Weldability: The capacity of a metal to be welded, under the fabrication conditions imposed, into a specific, suitably designed structure and to perfom satisfactorily in the intended service."

It has been suggested that our answer to the relative weldability of a material is a statement of the procedure required to weld that material for a given service.

III. WHY STUDY WELDABILITY?

It seems, by definition, that there are two general objectives involved in the activities of the Weldability Committee.

1. To establish a test or tests to evaluate the welding properties of a material without consideration of application, design or service requirements. Such a test might be considered for use in purchase specifications for material.

2. To establish tests which will assist the user of welding to evaluate the welding properties of a material with particular reference to application, design and service requirements.

The welding engineer is constantly confronted with the problem of not only selecting materials but also determining the proper welding methods and techniques to fabricate the materials into a suitable structure. Weldability tests are required in any program to develop or select weldable material or to determine optimum methods and techniques for a welding process. The development of tests for measuring the relative weldability of a steel has been the subject of extensive investigation. The factors which must be considered in the design or selection of weldability tests are numerous. The specimens should not be complicated in design, and it is desirable that a minimum amount of machine work be required. Test methods should be reproducible and have sufficient sensitivity so that the effect of changes in welding technique may be detected. Tests should also distinguish between the differences in the weldability of similar materials and be adaptable to studies including variations in thickness of the material. Finally, tests should be designed to approach the service requirements of the structure so far as rigidity, rate of loading, and temperature are concerned.

Any welding procedure may be complicated by a large number of variables, such as energy input, preheat and postheat temperatures, rate of energy input, chemical composition and mechanical properties of the base metal, welding sequence, joint design and constraint of the structure. In an attempt to simplify laboratory procedures, investigators usually consider only one or two of the variables at a time. This has brought about considerable confusion in the interpretation of weldability testing since each proponent of a test interprets his results in the light of variables which he has used in his investigation. In the comparison of tests, many of the methods of evaluating weldability will rate materials or procedures qualitatively in the same order—a quantitative evaluation is much more difficult.

Another consideration that is paramount in testing for weldability is the fact that most tests are laboratory tests from which it is desired to predict the performance of a material or process in a large structure. The relationship of small-scale laboratory tests to performance in the field structure, however, has not been quantitatively established. Only recently have testing temperature, degree of constraint and rate of loading been associated with the transition from ductile to brittle or cleavage-type fracture. It now appears that these factors will aid in establishing a quantitative relationship between large-scale and smaller-scale laboratory tests.

Another objective of any study of weldability is that of making as easy as possible the formulation of welding procedures necessary to weld a structure for a given service. Testing for weldability from a practical viewpoint may be twofold; first, to determine the response of a metal to various typical welding procedures, that is, an evaluation of the effect of a welding procedure on service properties and soundness of the welded joint under various degrees of restraint; and second, to find some practical method of evaluating the severity of a welding procedure and the degree of restraint imposed

by the procedure for the particular design of structure being fabricated. We are necessarily concerned with the design of the structure, as the design must be suitable for fabrication by welding and satisfactory for the intended service. In testing any material for weldability, usually the selection of the welding process is limited or predetermined by design, shop conditions or available equipment. The particular process is usually determined before the material is selected. The weldability of any given material may be dependent upon the welding process and the procedure used. Tests performed at any given level of power input may not be related to tests performed at some other level of power input. Tests performed using a given process may not be closely related to tests performed using a second process

Fundamentally, as a result of past work, there is agreement in our thinking regarding weldability if consideration is confined to deposited weld metal, effect of cooling rate, grain size and other factors which are related to the metallurgical response of the base material to the welding process. Since our thinking has expanded beyond this narrow field, we are apt to run into trouble because of conflicting ideas. Not too long ago, welding engineers would argue long and loud regarding metallurgical effects. We have shown some progress in this field as a result of a large amount of investigation which has taken place. It is natural that we should try to correlate weldability with a finished product. This approach involves fundamental effects of welding on microstructure and mechanical properties and requires a carefully thought-out systematic attack from a number of viewpoints. We still do not know how welding damages the mechanical behavior of steel. We do not know why and how welding generally raises the transition temperature.

In summary, the weldability of a material should be considered from an engineering standpoint and selected properties of that material must be evaluated in terms of service requirements; then the effect of welding on those properties becomes our paramount interest. Before using welding to fabricate any structure, from any material, it is desirable to procure information regarding the soundness and ductility over a range of temperatures correlated with service requirements. Our choice of a material for any given structure will depend upon the response of that material to welding, and laboratory tests should be aimed at providing this sort of information.

IV. WHAT HAS BEEN DONE IN THE FIELD OF WELDABILITY?

Investigations in the field of weldability and kindred fields have been very extensive. In addition to the effort which has been expended by the Weldability Committee of the Welding Research Council, vast programs have been carried out by industrial laboratories and government agencies, such as N.D.R.C., as well as Navy and Army laboratories. Some of these investigations have been interested in design and performance of structures. Many of the fundamental investigations, however, have dealt with the metallurgical effects of welding. Broadly speaking, a test for weldability consists of subjecting the material to the temperature cycle involved in the welding process and then evaluating the ductility of the resulting structures. The thermal cycle may be that obtained by an actual welding operation, or the effect of welding temperatures may be simulated by subjecting test samples to special heat-treatment routines.

The technical literature reveals that there are over 50 different specimens which have been used to evaluate some of the characteristics of weldments. These tests fall into four major categories: (1) weld metal tests; (2) tension tests of joints; (3) bend tests; and (4) fatigue tests. There are those tests that measure directly the effect of welding on the ductility of a steel, and also those that observe a change in some property, such as the maximum hardness of the heat-affected zone, and assume a direct correlation between this change and the resultant ductility.

The early tests for evaluating the suitability of a particular welding process for joining a particular type of material usually consisted of making a sample joint. The ductility of the resulting joint was then measured by tensile testing or bending. Such testing is still used in many applications for process approval, and the performance often depends upon the skill of the operator as much as upon the suitability of the process.

The hardness developed in the heat-affected zone contiguous to a weld deposit has attracted considerable attention. Usually the hardness of a transverse section of the heat-affected zone is explored by means of an instrument such as the Vickers, Knoop or Eberbach hardness tester. Several investigators have obtained considerable data from this simple test, which is almost universally used in conjunction with whatever other tests that may be performed. The maximum hardness method has always found wide use, since a hardness survey required a minimum of initial specimen preparation, and, similar to microscopic examination, the test imposes no limitation on welding technique and thickness of material. Its success, however, depends entirely upon the assumption that there is a satisfactory correlation between maximum hardness and ductility.

In many studies, in order to obtain additional information regarding the heat-affected zone, microscopic examinations were made of structures resulting from the welding thermal cycle on the assumption that ductility could be predicted from a careful evaluation of these structures. In general, such an evaluation for steels covering a wide range of weldability is not difficult, but specific, quantitative interpretation of results for steels over a narrow range of weldability is almost impossible. However, a microscopic examination of the cross section of a weld accomplished the following purposes: (1) it discloses both the quality and structure of the weld metal deposit and the metallurgical structure of the heat-affected zone which enables the metallurgist

to evaluate the cooling rate; (2) it provides a means of detecting microcracks; and (3) it permits the detection of segregation, laminations and inclusions in the steel. Such observations furnish pertinent information in any weldability study. Again, as in the use of the maximum hardness test, a microscopic examination must be made in conjunction with some other weldability test in examining steels over a narrow range of weldability.

The study of the thermal conditions and the metallurgical effects at the rates of cooling in the welding heat-treatment cycle has been frequently suggested. These data, together with the accepted views of metallurgical changes, may be used to predict the resulting ductility. Considerable attention has been given to the possibility of the application of isothermal and continuous cooling transformation studies. In all cases, an attempt has been made to evaluate the change in ductility of structures resulting from the heat treatment of the steel by the welding thermal cycle. A number of investigators have been interested in the use of the temperature relationships in the heat-affected zone and their metallurgical effects as a means for evaluating weldability. Aborn has pointed out that the properties of the heat-affected zone are the result of structural changes which are determined at any point by the maximum temperature, the length of time at that temperature and, more particularly, by the subsequent rate of cooling at that point; for this rate, if too great, will produce a zone of undesirable structure.

Hodell and Bruce developed formulas which were used to predict and control temperatures in the welding of oil well casing. An experimental program was carried out to measure the actual temperatures of cooling welds in the casing, and a close agreement was found between the analytical and experimental cooling curves. Hess, Merrill, Nippes and Bunk undertook the measurement of actual cooling rates in the heat-affected zone of single-vee groove welds. These data were used to modify fundamental mathematical solutions, and tables were prepared showing the energy in joules per inch required to produce any desired cooling rate at any selected temperature level for plate temperatures ranging from 37° F. (3° C.) to 400° F. (204° C.) and for plate thicknesses of $^1/_2$, 1 and $1^1/_2$ inches.

A number of tests have been suggested in which special heat-treatment techniques are used in an attempt to produce specimens with microstructures similar to those observed in the heat-affected zone.

One of the widely used direct tests for evaluating weldability is the tee-bend test sponsored by Bibber and described by Ellinger, Bissell and Williams. A double fillet tee-shaped specimen is tested as a guided bend specimen without removing any metal from the face of the weld. A special jig is used for bending the specimens and the angle of the head of the tee at maximum load is recorded, together with the load and type of fracture at failure. Bibber and Hueschkel have suggested the measurement of the energy absorbed in the bending as an additional index. It is interesting to note that the tee-bend test was the first test to differentiate between high-strength and low-strength steels. This was also the first of the bend tests requiring consideration of mode of failure, that is, ductile or brittle. It was felt that those steels which failed with a brittle fracture were less desirable for a welded structure, even though the angle at maximum load was satisfactory. The early investigators showed that the temperature of testing had an important effect on the angle of bend and mode of failure. It was felt that the tee-bend test integrated in the performance of a welded joint, the quality of the base metal, and the effect of the welding. There was no procedure for comparing base metal and welded specimens. Essentially, this testing procedure is applicable to comparatively low-hardenability structural steels, such as used in ship construction. However, there has been at least one attempt to apply the test to materials with higher hardenability, such as steels used in aircraft construction.

Kommerell and Bierett suggested an unnotched longitudinal bead weld specimen for determining the weldability of a manganese structural steel (St 52). The specimen, larger than those subsequently used by American investigators, was tested statically in a bending jig with the weld in tension. Two methods of evaluating the test were employed: (1) the measurement of the angle at which cracking first propagated into the base metal, and (2) the classification of the type of fracture either as a sudden fracture without appreciable previous deformation or as a gradual fracture after the development of a considerable degree of bending. In the early work of Kommerell and Bierett, the stipulation of a determinate bending angle was rejected, and it was required simply that the longitudinal bead-weld specimen should not exhibit any signs of brittle fracture. The test was generally considered extremely severe but, nevertheless, useful in evaluating the sensitivity of a steel to welding. However, difficulty was experienced in selecting an index which would be agreed upon as a guide to weldability. A recently reported investigation by Graff using the above test states: "As a specification test for 2-in. wide flange steel in the steel mill, it is recommended that a bend angle of at least 50°, better 60°, must be reached without fracture."

American investigators have found the longitudinal bead weld, slow-bend test to be probably the simplest, and most flexible of all ductility tests in lighter-gage, high-strength materials, such as aircraft steels. However, the success of the test in low-carbon steels is confined to the heavier gages. A modification of the longitudinal bead-weld specimen gaining popularity in this country comprises the use of a notch across the welded area, and more will be said later in this section relative to the application of the test in studying the effects of welding on steels.

Cornelius and Fashsel developed a notch-bend specimen comprising a transverse bead weld with a parallel notch machined so that its apex touched the fusion line. The specimen was bent around a pin until the first appearance of a crack at the root of the notch.

The angle of bend at failure was considered to provide a measure of the ability of the material in the heat-affected zone to undergo plastic deformation. This specimen has been modified by various investigators in an attempt to develop a test method in which the effect of welding on the behavior of the plate material can be compared with that of the unwelded plate. The slow-bend test is applicable to any thickness of steel plate, and the welding technique may be varied to suit practical limitations. It has been modified in a number of ways, including dimensions of the test specimen and the type of notch. Luther, *et al.*, presented the results of an investigation of the effect of welding on the temperature at which a change from ductile to brittle failure occurred. It was found that for a number of steels the temperature at which there was a transition from a ductile to brittle type of fracture in the unwelded type of plate was raised by welding.

One of the most intensive researches on steel weldability has been that concerning "hard" or "weld" cracking in the heat-affected zone of base metals in metal-arc welds. A number of test methods have been proposed for determining the underbead cracking tendency for a particular steel. Most of these have been more or less qualitative since wide variations usually cannot be avoided in the results.

Swinden and Reeve showed that, if severe restraint is imposed upon a welded joint in a low-alloy steel, cracking may result in the hardened zone. In addition, they described a restrained welded test piece which could be used to determine the conditions required to produce cracking. The test fillet of the Reeve specimen was made while restrained by previous construction. The development of this test was probably the first important step in the recognition of the need for measuring the crack sensitivity with respect to a restrained condition. Luther, Laxar and Jackson have described a cracking test based upon the degree of cracking in the heat-affected zones, contained in cross sections of bead welds. Transverse microsections were examined, and the amount of cracking present was qualitatively used as an index. Investigators at Battelle Memorial Institute have examined longitudinal sections of this same type of specimen in order to express the degree of cracking in per cent of total length of the bead.

The results of a number of investigations lead to the conclusion that cracking in the heat-affected zone of welds can occur whenever a critical combination of four factors is present. These factors are hydrogen, rate of heating and cooling, chemical composition and structure and stress. Suitable techniques reported for the control of cracking are:

1. Choose a ferritic welding electrode whose coating contains a minimum of hydrogen and water-bearing ingredients.
2. Choose an austenitic steel electrode.
3. Select a suitable preheating temperature, welding heat-input, or postheat treatment to ensure that after welding the transformation of austenite in the heat-affected zone can be made to occur at a high enough temperature so that martensite will not form or that hydrogen diffuses away from zones of high hydrogen concentration.
4. Choose a steel of minimum carbon and alloy content necessary for the particular service requirement.

The investigation conducted by Doan, Stout, Frye, and Tör provides an illustration of a systematic approach to the evaluation of the weldability of a steel. This work is significant, since for the first time an overall system was suggested for evaluating the weldability of a steel. The basic ideas presented in the tentative system for preserving ductility in weldments may be summarized as follows: (1) when a steel is welded, a definite maximum hardness is obtained which is dependent upon the cooling rate imposed by the welding operation; (2) equivalent hardnesses in the heat-affected zone and in the Jominy end-quench test bar may be taken to indicate equal cooling rates; and (3) each position on the Jominy bar represents a definite cooling rate and, consequently, corresponds to a certain combination of welding conditions. Therefore, equivalent hardnesses may be substituted for cooling rates and the hardness may be expressed in terms of Jominy distance. A notched bend specimen was used to establish the ductility hardness relationship since it was felt that ductility should be made the criterion for the hardened zone instead of hardness alone. The welding conditions were made universal with respect to joint geometry and plate thickness by virtue of having been modified by Stout's geometry factor.

An alternate method was later proposed which eliminated the use of the Jominy specimen and substituted for it a direct welding test in the form of simple bead-on-plate welds. Beads were deposited on plates with each bead deposited at a different energy input. The resulting variation in cooling rates with varying energy levels was reflected by a change in maximum hardness of the heat-affected zone of the base metal. As before, the bend angle accompanying each hardness level was then determined by a set of specimens cooled at different rates.

There is a general trend in weldability testing to the use of low temperatures as a determining variable, and all of the recent investigators consider that service performance of a steel or weldment is related to its transition temperature. The relationship between service performance and the temperature at which a bend or other type of specimen changes from a ductile to a brittle type of fracture has been studied by many investigators in this country. They have explored with prime plate, and a few have shown the importance of the effect of welding on the transition temperature.

In one of the earliest investigations concerned with the effect of temperature on the angle of bend of welded specimens, Houdremont, Schonrock and Wiester showed an increase in angle of bend from less than 20° to over 100° as the temperature of testing increased from 20 to 100° C. In this country a group at the Massachusetts

Institute of Technology, initially under the late Prof. A. V. deForest, undertook to investigate this method of approach to the weldability problem.

Much effort has been directed toward the determination of completely brittle fractures. It has been shown that the shape of the test specimen, the degree of constraint, the rate of loading and the temperature of testing were important in the investigation of any given material. Stout and McGeady investigated the effect of a number of variables on transition temperature. They showed that the most important variable which influences the properties of notch sensitivity and ductility of structural steels is the variation from one heat to another of the steel itself. Further, it was shown that the properties of the unwelded plate are not a reliable indication of the properties which will result when welding is performed on the plate. It is becoming increasingly evident, through continued research, that when structural steel is heated by welding to temperatures slightly below or within the critical range and then cooled moderately fast, high notch sensitivity characteristics are obtained. Anderson and Waggoner reported an investigation on the behavior of welded structural steel and on brittle fractures under service loading. They obtained a brittle fracture with some 2% elongation and reduction of area. They mentioned that due to restraint in a structure, accompanied by low temperatures, the yield strength of a structural steel can be raised to the ultimate strength, and that this eliminates the possibility of yielding.

Luther, Jackson and Hartbower reported the effect of welding on the transition temperature of a number of steels but found difficulty in correlating the results, since various test specimens indicated different performance. In a summary of welding tests of carbon and low-alloy steels, these same authors point out the need for fundamental information relative to the phenomenon of transition temperature.

Recently, a rather extensive report on the fracture of metal was prepared by Gensamer, *et al.* This survey was prepared and reported in order to form the basis for a long-time research program on the subject. The extensive discussion further emphasized the fact that even in homogeneous materials, the theoretical considerations and mechanism for transition temperature from ductile to brittle behavior are not well understood. The fact, that almost 300 references were given further, emphasized the fact that considerable investigation and thought have been given to this field of the investigation. It is mentioned that the most important factors which affect flow and fracture strengths appear to be stress combination, type of load, plastic strain, history, temperature, rate of strain, composition and metallurgical structures. At the present time it is impossible to quantitatively evaluate the effect of these various factors. In some cases, a qualitative statement may be made regarding the influence of a particular factor. Gensamer's statements have been related to the performance of the base material alone and have not considered the effect of welding on the base metal properties. Welding does not simplify the problem.

In the final report of a Board of Investigation to inquire into the Design and Methods and Construction of Welded Steel Merchant Vessels, it was concluded that the fractures in welded ships were caused by notches and by steel which was notch sensitive at operating temperatures. The highest incidence of fracture occurred under the combination of low temperature and heavy seas. It was felt that improved behavior can be provided by improved steel characteristics.

As a result of the failure of welded ships, extensive investigations of ship steels have been directed toward studying the mechanical and metallurgical aspects of the failures. These tests have included large- and small-scale specimens; in fact, tests have included vessels in service, replicas of welded hatch-corner construction, and all the standard and many ingenious nonstandard test specimens. At the present time, the mechanism of metal fracture is not well understood although concepts, such as the relation of resistance to flow and fracture and the change from ductile to brittle behavior with decreasing temperature, are being studied in attempts to elucidate the mechanism of brittle fractures.

In the past, the notched bar impact test has been used occasionally as an index of the ability of material to deform plastically under service conditions. The correlation has not been satisfying. A new approach to the phenomenon of plastic deformation has resulted from the greater understanding provided by recent experimentation, such as the work at Watertown Arsenal by Hollomon and Zener. For ferritic-pearlitic steels, the interrelation of radius to the notch, rate of applied load and temperature for plastic flow have been qualitatively proved and quantitatively indicated.

Bagsar, Kahn and Imbembo proposed cleavage-tear tests in which a notched tensile-bend type of test coupon was used. The effects of notch and coupon geometries, load eccentricity, rate of loading, testing temperature and of heat treatment were indicated by the work of Bagsar, whose test method is based upon a coupon which has sufficient rigidity and acuity of notch to assure development of cleavage fracture consistently. Rigid test coupons and sharp notches were used by Bagsar with the object of approaching conditions of stress and rigidity that may be encountered in all-welded monolithic structures in service. The test method proposed by Kahn and Imbembo was intended to define transition from shear to cleavage fracture in a manner which correlates with large-scale plate tests or similated service tests rather than to induce cleavage failure under all conditions.

One of the most recent works reported on ductility of steels for welded structures was the Campbell Memorial Lecture presented by Kinzel at the Annual convention of the A.S.M. in 1947. Kinzel concurred with contemporary investigators in that the trend in weldability testing is to use low temperature as a determining variable and to recognize that service performance of a steel structure is related to its transition temperature.

The phenomenon of decreased ductility with decreasing temperature was observed in many types of specimens. The choice of a particular specimen was dictated by ease of machining and testing. The specimen was tested in static loading as a simple beam loaded in the plane of the notch. The criterion suggested for the development of a brittle state or condition in a bend test specimen is the lateral contraction at the fracture. The embrittling temperature was defined as that at which approximately 1% lateral contraction occurred. The ratio of proportional limit to the maximum load approached unity under conditions that produced about 1% lateral contraction at fracture.

It was demonstrated that lowering of ductility with lowering of temperature is in no instance a proportional relationship. In some of the steels the lowering of ductility with temperature was gradual over a wide range of temperature. In many others, slight lowering of ductility occurred as the temperature was lowered until some rather narrow critical range of temperature was reached, when the loss of ductility was extremely rapid with lowering temperature.

Results of tests, wherein other factors than temperature were varied, showed (as expected by theory) that higher velocity of testing and greater degree of restraint acted in the same direction as lowering the temperature of test, that is, in increasing the proportion of the fracture which exhibited a brittle, coarse, crystalline appearance.

One of the findings of these comprehensive tests of most interest to designers, therefore, was that the deleterious effect of restraint in the structure has not been overemphasized in recent literature. In this regard the welding engineer also has great responsibility to specify the proper cycle of operations to minimize the restraint imposed by the differential heat effects of the welding operation, and to insist on proper preliminary heat treatment (normalizing) or postheat treatment (stress relief heat treatment) when such treatment is necessary. Notwithstanding previous statements, there is probably little doubt that the quantitative relationship between small-scale laboratory tests and the performance of full-scale structures can be established only by the systematic laboratory investigation of small-scale specimens run concurrently with tests on large-scale members that actually represent elements of a full-scale structure. Similar tests might be performed on actual failures as "post-mortem" studies of the behavior of the casualty structure.

V. WHAT HAS THE WELDING RESEARCH COUNCIL SUPPORTED?

The Welding Research Council, under the auspices of the Weldability Committee, together with the former Subcommittee II of the Industrial Research Division, have been interested in the investigation of weldability since 1937. In this period, covering over ten years, the emphasis of the work has gradually changed from that of a simple hardness survey to one concerned with the effect of welding on the behavior of base metal and weld metal when tested under varying degrees of restraint over a range of temperatures. Projects have been set up under various subcommittees at Battelle Memorial Institute, Lehigh University, Rensselaer Polytechnic Institute, Massachusetts Institute of Technology and the University of California at Los Angeles. In addition, there has been close cooperation with various industrial and government agencies. Other committees of the Welding Research Council have also contributed to our general information regarding weldability; notable is the work of the Structural Committee in their tests of large girders and structural I-beams.

The following sections briefly describe the programs which have been covered by those organizations directly responsible to the Weldability Committee of the Welding Research Council.

Battelle Memorial Institute. In June of 1941, as a result of a research program prepared by Subcommittee II of the Industrial Research Division, a research project on the problem of weldability was begun at Battelle Memorial Institute.

The broad objective of the investigation was to evaluate the influence of carbon and manganese on the weldability of the carbon-manganese steels. To paraphrase one of the early published reports of Subcommittee II, the essence of the problem was to obtain basic data which would lead to a better understanding concerning the avoidance of cracks during welding, and the maintenance of adequate ductility next to the weld to help prevent failure of the weldment under service loading. Two other objectives were ultimately brought into the picture; namely, an investigation of the usefulness of a notched-bead bend test for evaluating weldability, and an investigation of the adaptability of this test, in a modification of the Lehigh system,* for the evaluation or prediction of weldability. Throughout the research, an important objective was the development of a test for weldability of steels.

The work conducted at Battelle for the Welding Research Council on the weldability of the carbon-manganese steels may be divided into three periods. The first period began in June 1941, and ended in the summer of 1942, and dealt with the evaluation of underbead hardness as an index of weldability. Some tests were also conducted on the bending of bead-welded specimens, in an attempt to evaluate the ductility of the heat-affected zone. The initial program also included other tests (originally outlined by the Commitee on Carbon Steels) such as notched slow-bend and impact-bend tests of bead-welded plates, rigid-frame weld tests, tee-bend tests and tension impact tests. By the time the work had advanced through the first year, the Advisory Subcommittee felt that the latter tests should not be made, or at least deferred until the results of another investigation, on the weldability evaluation technique proposed by Kinzel (AWS Journal for October 1941) had been tried out.

The results of the research conducted at Battelle

* Guide to Weldability of Steels, A.W.S.

during the first period were submitted to the Welding Research Committee in five progress reports, and a paper describing all of this work was published in THE WELDING JOURNAL in 1942, along with a report of Committee II and three reports of other weldability tests on the same steels by other investigators.

In the interim between the first and the second researches on the weldability of carbon-manganese steels, Battelle conducted a research on the weldability of S.A.E. alloy steels, using the techniques developed in the first program, for the Watertown Arsenal. The results of these tests were published in THE WELDING JOURNAL for October 1943.

The second period of Battelle's investigations for the Welding Research Council began in November 1944, and ended in September 1946. As in the previous work, the underlying objective was to evaluate the influence of carbon and manganese on the weldability of the test steels, but the immediate objective was to evaluate the usefulness of the notched-bead slow-bend test as a means of measuring the weldability of steels, possibly in conjunction with a modified version of the Lehigh system.

At the start of the second period, three short pilot programs were conducted to investigate the most suitable bend specimen design, to determine the effect of aging on the behavior of the specimen and to obtain preliminary data on the possible effects of plate thickness and welding electrodes. When these tests had been completed and reported to the Welding Research Council, a paper was published summarizing the preliminary studies.

In August 1945, after about nine months of work on the pilot tests, the main program of the second period was begun. In this work, the notched-bead slow-bend test was used with all of the test steels available. The influence of variables such as electrode type, heat input, plate condition and plate composition on the bead-bend ductility of the welded specimens was studied. The results of these tests were presented to the Weldability Committee in a single progress report, and an abridged version of the report was published in THE WELDING JOURNAL.

The third period of the weldability investigations began in January 1947, and continued to April 1948. The work is an extension of the notched-bead slow-bend test studies, and entails a study of factors which had not been fully considered in the earlier investigations. The tests have included studies of the effects of proportionality of specimen dimensions on the behavior of the notched-bead slow-bend specimen; studies of the relative behavior of a pair of coarse- and fine-grained steels of similar chemical composition; and a study of the crack sensitivity of the test steels and the influence of preheat and electrode composition on the incidence of underbead cracking. Two progress reports have been submitted to the Weldability Committee on this work, but the data have not yet been published.

Lehigh University. In August of 1941, a cooperative study of weld cooling rates was established at Lehigh and Rensselaer Polytechnic Institute by the Welding Research Council with the object of obtaining data on the cooling rates associated with different welding conditions.

A system for controlling weld cooling rates was suggested by Kinzel, and subsequently developed at Lehigh. Given the minimum ductility necessary in the heat-affected zone of a welded joint in a structure, a technique was developed for (1) measuring the ductility corresponding to different weld quench hardness levels in the steel to be welded, using a series of notch bend specimens heat treated to various hardnesses; (2) setting up the welding procedure (current, voltage, speed and preheat) necessary to produce the required ductility in the joint.

The technical data necessary for the use of the system were published in THE WELDING JOURNAL for July 1943, *et seq.*, and in a separate booklet entitled "Guide to Weldability of Steels," published by the AMERICAN WELDING SOCIETY.

Later research at Lehigh obviated the need for the Jominy test by developing a direct hardenability determination using a bead weld specimen. This work was published in THE WELDING JOURNAL for December 1945.

In addition to the question of brittle structures in the heated zone of welds, there remained the problem of eliminating cracks in the weld metal or base metal which originate when the rigidity of the joint interferes with the natural shrinkage of the weld. No method of quantitatively gaging the effect of rigidity was known. Lehigh took up this problem under the N.D.R.C., and a specimen was developed which permitted continuous quantitative variation of restraint while the quench effect of the mass of the specimen was held constant. Using this test, called the restraint specimen, extensive studies of the crack susceptibility of different steels and electrodes were made. It was possible to detect significant differences in crack susceptibility between heats of the same S.A.E. type of steel. Differences among various brands of a particular A.W.S. type of electrode were revealed, while the different types were rated in order of crack susceptibility. Preheat of the base metal decreased susceptibility to cracking, particularly of low-alloy steels.

The restraint specimen was demonstrated to be a valuable tool in the study of both weld and base metal cracks. The above work was published in the A.W.S. JOURNAL for September 1946 and November 1947.

The crack-free properties of the 19–9 stainless electrode in the restraint test, and the good results reported by others investigating hydrogen-controlled electrode coatings for use in welding steels of high hardenability, led to an investigation of the effect of hydrogen on the properties of welds.

A longitudinal notch-bend specimen was developed at Lehigh and used for examining the effect of hydrogen on the notch sensitivity of welded structural steels. Also, Charpy specimens were heat treated in hydrogen and nitrogen atmospheres to simulate welding effects.

In both cases, the tests indicated that hydrogen has only a small effect on the transition temperatures of the structural steels studied. Results were published in the June 1947 WELDING JOURNAL.

Utilizing the Lehigh longitudinal notch bend specimen, a comprehensive survey of the effects of such factors as welding technique, preheating, postheating, steel composition and electrode type on the notch sensitivity of eleven ship steels was carried out under N.D.R.C.-Navy sponsorship. This work was reported in the June 1947 WELDING JOURNAL. The importance of the weld-heated zone in determining the notch sensitivity of the welded plate as a whole was emphasized during this work and led to further inquiry into the properties of the structures present in the heated zone. It was at this point, July 1946, that sponsorship was resumed by the Welding Research Council.

During the first year, it was found that base plate heated to intercritical temperatures possessed poor notch resistance. Cracking under external loading was shown to originate in the coarse grains of the heated zone, but rapid propagation of the crack may not occur until it penetrates to the area heated to intercritical temperatures. Studies showed that the notch resistance of the welded plate could be improved by such procedures as (1) pretreatment of the plate, such as hardening and tempering, and (2) postheating (probably because of metallurgical effects). Localized postheating by means of gas torches was shown to offer some hope as a cheap, practical means of improving notch resistance. These investigations were reported in the November 1947 WELDING JOURNAL.

Rensselaer Polytechnic Institute. The principal contribution of this laboratory to the weldability investigations, begun in the fall of 1941, has been the quantitative measurement of cooling rates associated with arc welding conditions. The cooling curves were measured by insertion of thermocouples located so as to measure the maximum cooling rates existing in the heat-affected zone immediately adjacent to the area of fusion. The experimental measurements permitted the development of a precise mathematical relationship between the welding variables and cooling rate. The mathematical relationship allowed the prediction of cooling rates associated with any combination of welding variables within the limits studied, thus giving wide extension to the experimental data.

The factors found significant in their effect on weld cooling rates were the following: (1) weld energy input, (2) plate thickness, (3) plate temperature and (4) joint geometry.

The arc voltage, arc current and electrode travel speed were grouped in the single variable, energy input. The energy input is expressed in electrical units or joules per unit length of weld. Careful experimental investigations showed that the thermal properties, conductivity and specific heat, vary so little between plain carbon and a variety of low-alloy steels, that the cooling rate is not affected in any significant manner. The size of the arc-welding electrode was shown to have a very small effect on cooling rate. The type of electrode employed, whether mild steel of any of the common types, low alloy with or without a lime-type coating, or austenitic or base electrode, produced no significant difference in cooling rate. The above relations were found for butt welds in steel plate. When fillet welds were made, the type of mild steel electrode has a slight effect on the cooling rate owing to the different shape of the deposited fillet, whether convex or concave.

Energy inputs were varied from about 15,000 to more than 100,000 joules per inch. Arc travel speed was varied between 5 and 12 in. per minute. Arc welding electrodes between $^1/_8$ and $^1/_4$ in. in diameter were employed. Arc voltages and welding currents were varied within the ranges recommended by the manufacturers. Plate thickness was varied between $^1/_4$ and $1^1/_2$ in. Plate thicknesses up to $^1/_2$ in. were found to cool in the manner of a thin plate, the heat being dissipated only laterally away from the weld. On the other hand, plate thicknesses of 1 in. or more cooled as plates of infinite thickness, that is, heat dissipated through the thickness of the plate as well as laterally for the values of energy input used in this investigation.

In studying the effect of plate temperature on cooling rates, temperatures from 37° to 400° F. were employed. Plate temperature and weld energy input provide the principal independent variables for the control of weld cooling rate.

The majority of work in these investigations was done with butt welds or simulated butt welds in flat plate. In simulated butt welds, the plates were grooved to permit the deposition of the last pass of the butt weld which was shown to be the most significant with regard to cooling rate. The only other joint geometry investigated was a tee-joint between $^1/_2$-in. plates. Cooling rate data are, therefore, not available for tee-joints in either dissimilar thickness combinations or thicknesses other than $^1/_2$ in. The tee-joint studies showed that, whereas the last pass of a butt weld cooled most rapidly, the first pass of a fillet weld in a tee-joint cooled most rapidly.

The careful study and determination of the cooling rates associated with arc welding, raised the question as to how to determine the proper welding conditions for any given steel. A method of applying the cooling rate data to the problem of predicting welding conditions for different steels has been successfully established. The basis of this method involves measuring the response of the steel to a variety of different cooling rates, and selecting welding conditions to give the desired metallurgical structure. Mechanical properties are presumed to be related to metallurgical structure.

Another phase of the weldability studies involved further experimental measurements which led to the formulation of mathematical expressions for the time-temperature curves representing the complete heating and cooling cycle experienced by any point in the vicinity of an arc weld. The validity of these mathematical expressions was checked by direct measure-

ments under a variety of welding conditions. The determination of the complete thermal cycles experienced in the vicinity of an arc weld opens up a wide opportunity for the study of the effects of welding heat upon steel.

The cooling rate data were utilized to study the effect of this variable on the impact strength-temperature relationships for the various metallurgical structures found in the vicinity of arc welds. Charpy impact strength-temperature relationships were also determined for the weld metal, as well as the adjacent zones. The weld metal quality, as measured by impact strength and transition temperature, was not appreciably affected within the range investigated, by arc power level, arc travel speed, cooling rate and preheat temperature. The region of carbide coalescence or spheroidization had the highest transition temperature of the structures tested. The impact characteristics of the spheroidized region were not affected by arc power level or arc travel speed, but were affected by the cooling rate adjacent to the weld, and the preheat temperature. The lowest transition temperature was obtained with intermediate cooling rates. A preheat temperature of 400° F. was found to affect adversely the transition temperature for welds made with constant cooling rate.

Although the notch in a standard Charpy specimen can be placed in any desired zone adjacent to an arc weld, the impact failure tends to traverse different metallurgical structures. For example, fractures which initiate in the spheroidized zone traverse large regions of relatively unaffected plate metal. Likewise, when the notch is located in the coarse-grained zone, fracture traverses coarse-grained, fine-grained and spheroidized zones.

Massachusetts Institute of Technology. Work for the Welding Research Council on the DeForest Brittle Temperature Project started in April 1945. This program was a continuation of the work which was originally suggested by Dr. deForest and sponsored by the N.D.R.C. The program has been strictly a fundamental research investigation aimed at untangling the relationships of transition temperature and method of testing of various steels with various welding techniques.

The work carried out on the brittle temperature project has been based on a special slow-bend test utilized to accurately determine the temperature of transition to brittle fracture under well-controlled strain rates and testing temperatures. The test method is that of observing, for a given notch specimen in bending, the plastic deformation in a load-deflection record. Automatic plots of load and deflection are used to ensure obtaining the transition temperature accurately. Materials tested include welded and unwelded semikilled ship plate, mild steel, silicon-killed, high tensile steel, wrought iron and others. Comparison of transition temperature and various parts of two double-vee welded ship plates of nonkilled steel showed that the deposited weld material at the weld center was far superior to that of the adjacent base plate material, and slightly better than unwelded semikilled plate tested to the present time. In two welds, the base material 1 in. from the weld center has been shown to be the most brittle with a transition temperature 100° F. higher than the transition temperature at the center of the weld. In addition, the effects of constraint or of combined stress ratios on the combined transition temperatures have been determined. It has been shown that at a given strain rate the transition temperatures were raised by at least 100° F. when proceeding from uniaxial to biaxial conditions. The investigation on the comparison between notch bars and simple structures shows that a single notch bar could be selected to give the same transition temperature at the same strain rate as the given structure, and that the comparison was a purely formal one independent of material. Tests have been conducted in which the transition temperatures of the M.I.T. slow-bend tests were compared with those of the standard Charpy impact test.

A special study was made to determine the effects of prior cycles of fatigue on the transition temperatures for brittle fracture in an S.A.E. 1020 steel. The results show that the transition temperature was increased very materially, as a number of prior fatigue cycles increased, for stresses both above and below the endurance limit.

VI. WHAT IS UNDER WAY OR PLANNED?

Battelle Memorial Institute. To summarize briefly, the work conducted for the Welding Research Council at Battelle Memorial Institute on the weldability of the carbon-manganese steels during the past seven years has produced numerous data on the hardening characteristics of the steels adjacent to welds, the crack sensitivity of the steels, the capacity of welded sections of the steels to deform under load at room temperature and on the influence of welding technique factors such as electrode type and cooling rate. It is believed that additional tests are necessary on some phases of the work in order to make the available data more applicable for use by the industry. Among these problems are:

1. Evaluation of the cooling rates used in the crack-sensitivity studies, and crack-sensitivity tests on $^1/_4$- and $^1/_2$-in. plates of the test steels, to add to the data now available on 1-in. thicknesses, to determine if the crack sensitivity tends to change with plate thickness (i.e., change in the steel characteristics rather than in the cooling rate). Studies to determine the required cooling rate for maximum cracking are also desirable (recent tests on other types of steel indicate that the maximum cracking does not necessarily occur at the fastest cooling rates).

2. Studies of the metallurgical characteristics and hardenability properties of coarse- and fine-grained steels of the same chemical compositions, to determine, for heating and cooling rates approximating those used in metal-arc welding, the grain coarsening, hardenability and ductility characteristics of the base metal.

3. Evaluation of the behavior of welded specimens of the carbon-manganese steels, under deforming loads at a series of temperatures (transition-temperature studies).

4. A study of the differences in the welding behavior of cast and wrought carbon-manganese steels of the same composition.

Lehigh University. Lehigh University has been authorized by the subcommittee to proceed with the following program:

1. Study further the various criteria for evaluating the results of transition temperature tests.

2. Study additional carbon-manganese steels with the idea of covering the range of steels in present-day commercial use. To cover commercial carbon-manganese steels, it was suggested that extremes of analysis, melting practice and thickness of the following steels be tested: A.S.T.M. A-201, 212, 283 and 285. It would be desirable to obtain some of the steel used for the beam impact tests at Columbia University and some of the Ship Structures Committee Steels, the former for a check with actual structures.

3. If time permits, make pilot tests of the effect of the residual stress on the transition using the Lehigh fin specimen.

Rensselaer Polytechnic Institute. The present program involves a method of producing a particular structure uniformly across the entire test section. The method is based upon previously established time-temperature relationships at various distances from the weld center line as a function of welding variables. Since the metallurgical structure produced in the plate material near an arc weld is a result of the thermal cycle at the point of interest, exact duplication of a desired metallurgical structure may be accomplished by subjecting a specimen of convenient size to the proper thermal cycle by electrical resistance heating. Special equipment has been built in order to control automatically the electric resistance heating to duplicate exactly the heating and cooling cycle of the weld. This equipment will be applied to a series of different steels to show the effect of welding heat on the transition temperature curves. In order to complete the picture, it will be necessary to study separately the different heat-affected zones to determine which is affected to the greatest extent by the heat of welding. Furthermore, it is hoped that opportunity will be provided to extend the program to study the effect of strain-aging, and also the effect of impurities such as nitrogen on the notch impact properties of a variety of steels.

A further program, which this laboratory is very desirous of undertaking is the study of cooling rates produced by welding conditions involving higher power levels and greater travel speed than those used in the previous investigations. Other work has shown that these cooling rates should be of great interest in helping to explain the results obtained with the higher travel speeds associated with special welding techniques and submerged-melt welding. The prior experience and facilities available in this laboratory are ideally suited to the performance of such an investigation.

Massachusetts Institute of Technology. The investigation is aimed to study the possible effects of metallographic structure on the fracture properties of a low-carbon steel. The essential part of the experimental technique is to vary the pearlite distribution (spacing of pearlitic lamellae) while keeping all other factors, including grain size, the same.

The steel under investigation is a killed steel; check analysis: carbon—0.17%, manganese—0.48%, phosphorus—0.012%, sulphur—0.039%, silicon—0.09%; mechanical properties: yield point—35,520 psi., tensile strength—58,390 psi. (nominal), elongation in 8 in.—26.0%; the plate is $^3/_4$ in. thick as-received.

The steel when austenitized at temperatures from 1550–1750° F. yielded a fine-grained structure. Austenitizing between 1850 and 2000° F. resulted in a coarse-grained structure. By a suitable hot quenching technique it was possible to produce samples with coarse and fine pearlite spacings in both fine- and coarse-grained steels. These steels were slow bend tested by the method described previously, and the following preliminary results were indicated:

(*a*) The steel that was fine-grained had considerably more ductility as measured by the embrittling temperature than the coarse-grained steel.

(*b*) Increasing the fineness of pearlite spacing tends to yield the same effect as a decrease in grain size. The samples with a combination of fine pearlite and fine grain size displayed the most ductile properties under the test conditions.

Further work is planned to separate the two variables present in these preliminary tests, namely, the amount of free ferrite present and the pearlite fineness. It is planned to accomplish this by using a steel of eutectoid composition for a similar series of tests. This will eliminate the ferrite factor.

Other work is under way to demonstrate the correlation between the type of brittle fracture obtained in the M.I.T. tests and that obtained in other tests. The main difference between the M.I.T. criterion and the others is that the embrittling temperature reported is the maximum temperature at which no plastic deformation takes place prior to failure. In many other tests which measure transition temperatures, the steel is plastically deformed before failure takes place. It is expected that this work will also aid in selecting the most useful criteria for determining embrittling temperatures.

University of California at Los Angeles. During the past year a program has been organized at the University of California at Los Angeles. This program has been based on results obtained in a recent investigation which showed that mild steel arc welds were embrittled to a remarkable extent when subjected to a treatment consisting of a 2$^1/_2$% tensile strain, followed by storage or aging at room temperature for several days. The degree of em-

brittlement appeared to be considerably greater than attributable to the effects of strain-hardening alone. Since a $2^1/_2\%$ deformation appears to be so effective in introducing brittle behavior, the question has been raised whether plastic straining of weld metal during the cooling which follows deposition or during cold forming after welding, may not have a similar influence. The Subcommittee has been set up to confer with the investigators and a definite proposal has been approved.

VII. WHERE ARE WE, AND WHERE ARE WE GOING?

After considering the weldability programs which are under the direct sponsorship of the Welding Research Council, as well as the many investigations undertaken by other organizations, it becomes evident that effort has been very heterogeneous. There is need for unification, there is need for simplification and reorganization. Such effort can only be carried out by the Weldability Committee as a whole, since most individual investigators or engineers are probably prejudiced by their particular viewpoint and experience. From an over-all viewpoint, investigations of the Welding Research Council have contributed extensively to the progress in the field of weldability.

As a result of the many investigations in the field of weldability, we have reached certain tentative conclusions which are listed below. No attempt has been made to present these items in order of importance.

1. Cracking: It is evident that performance of any welded structure is probably dependent upon the tendency toward cracking. Studies have been reported, by both American and British investigators, which have been concerned with cracking. Testing procedures for the study of cracking tendency, both in base metal and weld metal, are well developed, although additional investigation is called for to produce a complete statement of the mechanism of cracking.

2. Type of Specimen: There is a general feeling that most of the specimens which have been suggested are satisfactory for the determination of transition temperature for the particular restraint and rate of loading presented by each specimen. It is desirable to increase the restraint of the specimen by notching so that testing procedures required can be easily obtained in the laboratory. Three types of welded specimens have probably received the most favorable consideration. These are the tee-bend and two simple beam or slow-bend specimens with weld beads either transverse or longitudinal to the specimen. Each of these three tests has certain advantages which make it useful for particular investigations. The most important advantage of the slow-bend specimen is that plate specimens may be compared with welded specimens.

3. Criteria: In the interpretation of results of mechanical tests, a large number of criteria have been suggested. At the present time, some correlation has been shown between these criteria, although this correlation has been qualitative instead of quantitative. Among others, the following criteria have been used by various investigators: angle of bend at maximum load, per cent of shear in the fracture, energy absorption, maximum load, lateral contraction and ratio of yield to tensile loads. It has been recommended that considerable effort should be put forth to include as many of these measurements as possible in reporting future investigations.

4. Effect of Previous Deformation: It has been clearly demonstrated that deformation will raise the temperature for brittle failure. In any bend test, of course, the type of fracture will be influenced by the amount of deformation which the specimen undergoes before failure. Hence, in a material in which the temperature for brittle fracture is influenced by previous deformation, the fracture may be brittle after considerable deformation. It is felt that the effect of previous deformation and the tendency for brittle fracture in a steel should be considered separately in studying the behavior of welded test specimens. Obviously, a test in which the material fractures brittlely after considerable deformation is not an indication of the properties of the material before testing. Hence, the use of 1% lateral contraction, small angles of bend or low energy absorption, such as 15 ft.-lb., as a criterion for transition temperature, seems to be more logical than 50% shear or one-half maximum energy.

5. Thickness of Specimen and Span: Some testing has been undertaken in which the thickness dimension of the specimen has been varied. This variable complicates the interpretation of results, as an increase in the thickness of the specimen is effective in two ways; namely (1) the cooling rate during welding becomes more drastic as the thickness increases, and (2) the restraint, using a given span for testing, becomes greater as the thickness of the specimen is increased. This leads to a conclusion that the welding conditions and span should be adjusted proportionally, to provide similar results if the investigator is interested in measuring the properties of a material. If testing is carried out to investigate the performance of a material in any particular design, then the influence of thickness might well be studied with a single span. So far little information is available which will permit the translation of results with a given restraint to those with a second degree of restraint.

6. Composition: Most of the investigators have shown that carbon is by far the most critical element in a material which may be used for a welded structure. British investigators have shown that improved performance is obtained with materials having a ratio of manganese to carbon of at least three. The effects of carbon and manganese have been considered in investigations carried on at Battelle Memorial Institute. Additional investigators have considered the effect of silicon, nickel and other alloying elements. It appears that most of the alloying elements are less detrimental than carbon in materials with a given tensile strength. Further information is needed for exact evaluation of

the effect of composition, particularly from the viewpoint of transition temperature.

7. Welding Technique: A number of investigators have shown the effect of increasing current or change in rate of travel on the performance of welded test specimens. It has been shown that faster rates of heat input, with high currents, produce a narrower heat-affected zone with better transition properties than obtained for a weld produced at a low rate of travel with low currents. There is still need for an over-all survey showing the effect of welding technique on the performance of welded test specimens.

8. Structure and Grain Size: A number of investigators have attempted to determine the effect of microstructural changes, such as the distribution of the pearlite-ferrite phases. The investigations regarding grain size (McQuaid-Ehn) have been rather unsatisfactory. There has been some tendency for improved performance with those steels having a fine grain treatment.

9. Restraint: A number of investigators have observed the performance of specimens with various types of notches. However, before much additional progress can be made in this field, some quantitative method of evaluating restraint is urgently needed. As restraint is increased, the transition temperature for most steels will be increased. The rate of increase may vary from steel to steel. A qualitative evaluation of restraint may be had by giving the ratio of the yield to maximum loads; the ratio will increase with restraint.

10. Brittleness: Considerable discussion and some preliminary investigations have been made to determine the factors controlling the brittle fracture of steels. It appears to be associated with the mechanism of slip in the crystal structure of the material being studied. Austenitic materials show a greater possibility for the formation of slip planes, whereas, the ferritic materials have a tendency to restrict slipping due to a difference in crystal structure. Little information is available regarding the effect of composition on brittle behavior, except for the fact that an increased carbon content tends to raise the transition temperature.

X-ray analysis on large crystals fractured at low temperatures has confirmed that the planes of brittle fracture are parallel with the cube faces of the crystal. Intercrystalline fracture is not excluded, particularly when the carbide forms intercrystalline films in low-carbon steels, which have been slowly cooled. Associated with the main fracture, there are often small secondary cracks exhibiting similar features. There are little data available which will assist us in explaining the mechanism of brittle failure. Additional studies using X-ray and microscopic examination would be useful. Changes in physical properties, such as tensile strength, using the common 0.505-in. diameter tensile specimen, have not been significant as the temperature is decreased. One series of tests in which the hardness of a number of steels was measured from room temperature to -180° C., showed a gradual increase in hardness for materials containing alloying elements and higher carbon. For low-carbon materials there was a discontinuity in the temperature-hardness relationship. No correlation was possible between this break in the hardness-temperature curve and transition temperature, as measured by the usual slow-bend specimens. It was felt, however, that the use of microhardness might reduce the effects of deformation in the hardness test and give hardnesses more nearly approaching the actual hardness of the specimen. Possibly the discontinuity in the hardness-temperature curve might be related to some change in the capacity for slip formation in the low-carbon steels as the temperature decreases.

Other studies which would be useful would include an accurate evaluation of the effect of gases, such as nitrogen and oxygen, on the brittle behavior of steels. One of the laboratories has reported its intension of obtaining basic information concerning the low-temperature properties of relatively pure iron alloys, beginning with binary compounds. There is need for emphasis of the theoretical considerations of brittle behavior of steels. This may be one of the most important items confronting the metallurgy of weldability.

11. Notch Geometry: In many of the test specimens, notches are used to restrict the deformation to a small area of the specimen under the root of the notch. There is no clear concept of the effect of various notch dimensions, except that qualitatively the sharper notch will restrict the deformation to a smaller area. As the sharpness of the notch is increased, the ratio of the yield strength to tensile strength in a slow-bend test will be increased until brittle failures will occur, with yield strength to tensile strength ratios of 0.90 to 1.00.

12. Rate of Loading: The tests at M.I.T., used with variable rates of loading, have confirmed the fact that there is a linear relationship between the log of the deflection velocity (in in. per second) and the reciprocal of absolute temperature. An increased rate of loading will, in general, raise the temperature for brittle fracture, although Dorn has indicated that the relation between strain rate and temperature may not be rigorous.

13. Type of Electrode: Several investigators have studied the effect of various electrodes. For a given welding technique, little difference can be shown in the heat effects of various electrodes. Variations in electrodes have included composition as well as type. In the work at Battelle, it was shown that different types of electrodes have no significant influence on the bending behavior of the welded specimen. The hardness in the heat-affected zone is not influenced by the characteristics of the coating or shielding atmosphere, but only by the welding current, welding speed, preheat and plate thickness. There is, however, a decided effect of various electrodes when the cracking tendency of the weld metal or base metal is considered. The present investigations have shown that cold cracking is produced under unfavorable welding conditions with any of the electrodes whose coatings are not specifically designed to generate only small quantities of hydrogen (classes E-6010, E-6012 and E-6020). On the other hand, when a low-hydrogen, ferritic electrode (Class

E-6015) is used, no underbead cracking occurs even with unfavorable conditions of cooling rate and steel composition. The work at Lehigh has demonstrated that various electrodes will have different tendencies of forming weld cracks.

14. Effect of Heat Treatment: Various investigators have pointed out the effect of heat treatment of the base metal on weldability. It is generally accepted that a full heat treatment, consisting of quenching and tempering, improves the performance of a steel which is to be welded. In cast steels, normalizing before welding has been shown to be particularly useful. Stress-relief annealing, either by furnace treatment or local treatment, has shown an improvement in the performance of welded structures. No over-all survey of the importance of heat treatment on weldability is available.

VIII. WHAT REMAINS TO BE DONE?

1. Criteria: The investigators at Lehigh are, at the present time, engaged in an evaluation of the various criteria which have been used for designating quantitatively the transition temperature. Care should be taken to report all measurements, and considerable thought and effort, perhaps even of a somewhat philosophical nature, must be expended in this field in order to correlate laboratory tests with service performance.

2. Type of Test: The work at Battelle, under the sponsorship of the Navy, has been aimed at the selection of a test specimen which will correlate with service performance. This program will also include the study of criteria and some consideration of materials.

3. Effect of Thickness: Considerable confusion regarding the effect of thickness in transition behavior is evident. There is need for a study showing the effect of thickness and its relation to span and width of specimen. The work with the tee-bend test supports the use of proportional jigs in material studies.

4. Effect of Composition: Little work has been carried out on the effect of composition on transition temperature. The series of carbon-manganese steels available at Battelle would be useful in this study, and it is hoped that investigations will be set up including a determination of the transition temperature of these materials.

5. Effect of Structure: The studies at R.P.I. and M.I.T., as well as some aspects of the work at Lehigh, have been interested in determining the effect of structure on transition temperature. This work has included fully hardened structures, stuctures which have been heated to temperatures between the criticals, as-rolled, normalized and tempered materials including steels made by different processes.

6. Measure of Restraint: Although a quantitative evaluation of restraint may not be in the province of the activities of the Weldability Committee, it would be highly beneficial to the work of the committee if it were possible to quantitatively evaluate restraint. Such an evaluation should provide a means for correlating the various test specimens and data which have been obtained using various specimens and testing procedures. At the present time, the ratio of the yield strength to tensile strength seems to be the only logical approach.

7. Experience Table: For some years, investigators at Lehigh have suggested correlation of laboratory tests with service failures. This would require the investigation of structures which have failed and structures which have proved satisfactory, in order to determine the relationship of laboratory tests to service properties. It is felt that this is a long-time project, and the availability of failed structures will determine its progress.

8. Nonferrous Materials: Although the weldability of nonferrous materials is of great concern to some fabricators, little or no work has been carried out aimed at the quantitative evaluation of weldability of nonferrous materials. An attempt should be made to apply some of the test pieces which are available for ferrous materials.

9. Transition Temperature: There is still urgent need for a theoretical philosophy which would explain the factors that influence transition temperature. The fundamental causes for the phenomenon usually referred to as transition temperature in steel are still a question of great concern.

10. Effect of Power Input: There is need for additional information which will extend the work carried out at R.P.I. in their study of the effect of welding technique on cooling rates. Higher rates of travel, outside of the rather limited range which they studied, should be included. There is some indication that the rate at which the power is supplied to a plate will control the width of the heat-affected zone. There is need for further information regarding the cooling rates for standard welding conditions, such as those used in the Battelle cracking test.

11. Aging: Some investigators have shown that the ductility of welded bend test specimens improves with age. The reasons for this improvement are not clearly understood. Other investigators report no improvement of ductility with age. It is possible that this improvement is related to the electrode type or steel properties. There is some evidence that there is a difference in the aging effects with different brands of E-6010 electrodes.

12. Cast Steels: A number of investigators have shown that the cracking tendency for cast steels is somewhat less than that for wrought steel. It appears that the hardness level at which underbead cracking begins to be present is from 50 to 100 Vickers higher in a cast steel than in a wrought steel. Further clarification of this relationship would be useful.

13. Test Conditions: There is need, especially for the work of the Weldability Committee, for setting up a minimum number of weld test conditions. This would be useful in order that the work of the various investigators might be better correlated.

14. Underbead Cracking: Little or no work has been carried out showing the effect of thinner sections on

underbead cracking. Tests should be set up to investigate the underbead cracking tendencies of materials in $^1/_4$- and $^1/_2$-in. thicknesses. We need to know more about the effect on cracking of inclusions and alloy segregation, of cooling rates in the ingot phase, heating times in the slab, and rolling procedure. Although the role of carbon is pretty well established, the effect of individual elements and elements in popular combinations are not.

15. Effect of Previous Deformation: Since brittle fractures may occur after considerable previous deformation, it is important that quantitative information be obtained regarding the effect of previous deformation on the properties of a steel. Some work is under way under the jurisdiction of the Pressure Vessel Committee. It is felt that welds may have entirely different behavior when deformed than when used in the stress-relieved condition. Such an investigation has been initiated at U.C.L.A. and will include studies of weld metal as well as composite welded structures. There should be further investigation of the effect on transition temperature of fatigue cycles both below and above the endurance limit.

IX. HOW CAN WE USE OUR PRESENT KNOWLEDGE?

From qualitative studies of the effect of transition temperature, it has been shown that carbon is the most effective element in the composition of the steel in raising transition temperature. For a given hardness or tensile strength, steel with the lowest carbon generally shows the lowest transition temperature.

There is ample proof that quenching, followed by tempering of a steel, lowers the transition temperature. The question of transition temperature from this viewpoint is not a metallurgical problem, but must be considered as an economic problem, since many applications do not warrant the additional cost of full heat treatment. There is confirmation of the fact originally reported by the M.I.T. investigators, that the zone of maximum hardness may not be the most critical structure in the heat-affected zone. It has been shown at Lehigh that cracks originating in the hardened structure will propagate much more rapidly across a wide zone which has been heated to a temperature between the lower and upper criticals. In fact, the width of the zone which has been heated to the critical temperature will probably control the behavior of the welded specimen.

A number of investigators have reported improved behavior for steels which have been fully deoxidized. Rimmed steels, in general, have shown high transition temperatures, although an occasional heat of rimmed steel is encountered with excellent behavior. Semi-killed steels, in general, are intermediate between the fully deoxidized and rimmed steel.

In the welding of medium alloy steels, such as S.A.E. 4130, it has been demonstrated that the effect of preheat is mainly one of controlling the cooling rate obtained after welding. The use of sufficient preheat and postheat to ensure complete transformation of the heat-affected zone to bainitic structures has been shown to improve the ductility of the welded specimen. This has had rather close correlation with transformation observed from isothermal diagrams. A preheat and postheat of 700° F. has given the shortest time for transformation for many alloy steels.

The work at M.I.T. has confirmed the effect of increased rate of loading in raising the transition temperature, although recent work by Dorn has indicated that the relation between strain rate and temperature may not be rigorous. Industrial laboratories and the work at M.I.T., under sponsorship of the Welding Research Council, have shown the influence of welding techniques on transition behavior.

Probably the most outstanding factor controlling the performance of steels for welded construction is the carbon content. All investigators have pointed out the importance of keeping the carbon content low for improved weldability. The maximum hardness obtained after drastic quenching is determined by the carbon content (Fig. 1). Hardnesses approaching the maximum attainable hardness may be encountered under drastic conditions of welding. With carbon content at 0.10%, the maximum hardness which might be attained by drastic quenching would be not more than 400 Vickers. Lower hardnesses will be obtained at the slower cooling rates which accompany welding under average conditions. The cooling rate attained in the heat-affected zone will be controlled by the weld nugget area. It is logical to assume that cooling rate will be slower for those weld beads for which the nugget of weld metal is larger, and by the same token, as the nugget area is decreased, the cooling rate in the heat-affected zone will become more drastic. Since the cooling rate will control the hardness attained in the heat-affected zone, it should be possible to show a relationship between nugget area and maximum Vickers hardness. This has been done for a plain carbon steel in Fig. 2. A rather sharp increase in hardness is obtained as the nugget area decreases below 0.04 sq. in. With lower carbon content, no increase in hardness, even under the drastic quench accompanying a small nugget area, will be found. By the use of Stout's geometry factors, plates of various thicknesses can be handled on a single plot. From the above figures, it can be seen that for some steels there is a critical nugget area and thickness, which will control rapid hardening.

There is a definite relationship between welding technique and the area of the nugget which is deposited. This relationship is approximately that shown in Fig. 3. With the nugget area for any given steel fairly definitely established for satisfactory performance, one must consider the effect of welding technique on penetration. From work that has been presented by the Swedish investigator R. Gunnert, the penetration may be given by the following formula

$$P = K \sqrt[3]{\frac{I^4}{VE^2}}$$

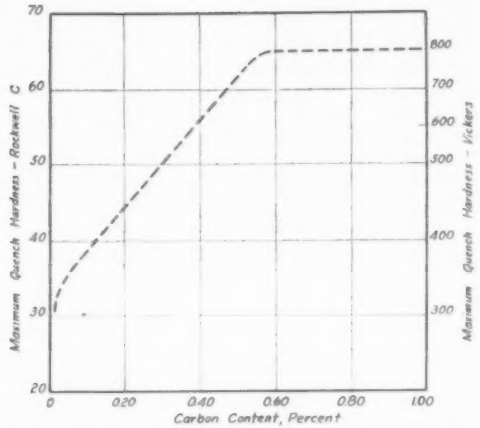


Fig. 1 Influence of carbon content on maximum quench hardness

where P is the penetration in in., I the current in amp. and V the speed of travel in in. per minute, E the voltage across the welding zone and K is a constant depending on the welding process which is being used. For E-6010 type of electrodes K will be equal to approximately 0.0012. This equation will be independent of thickness, providing the sheet acts as a thick plate. Rensselaer Polytechnic Institute has shown that a given welding technique will perform on a given plate as a thick plate when the ratio of welding energy to the thickness is low. In Fig. 4 is plotted data which show the relationship of penetration to the current, voltage and travel on 1-in. thick plate.

We are now in a position to evaluate the weldability in terms of room-temperature ductility if it is controlled by the maximum hardness. This relationship, however, shows a very wide scatter (Fig. 5). The maximum hardness is not an exact measurement of the room-temperature ductility in the heat-affected zone, because various structures react differently to previous deformation. If we consider the transition temperature or embrittling temperature at some low value of energy absorption or lateral contraction, then the relationship of hardness to transition temperature is somewhat more

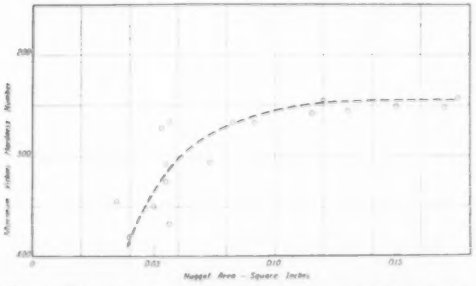


Fig. 2 Effect of nugget area on maximum Vickers hardness number

Steel No. 23: C = 0.28%, Mn = 0.53%, Si = 0.08%

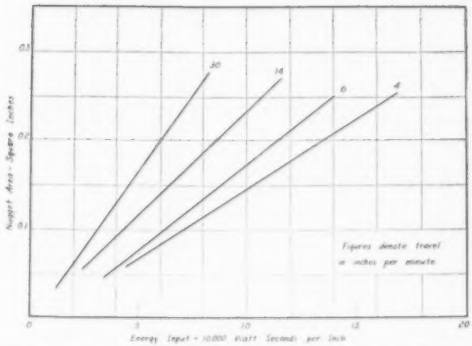


Fig. 3 Relation of nugget area to energy input at various speeds of travel

significant. Both Stout and Kinzel have presented data which show some degree of correlation between transition temperature and hardness. This is shown in Figs. 6 and 7. Stout has also shown that transition temperature, based on 50% shear, is related to the carbon content (Fig. 8). These relationships are presented and assume a given specified testing procedure. Other conditions of test which increase the rate of loading will, in general, raise the transition temperature (Fig. 9). This increase in transition temperature is probably characteristic of each steel which might be tested. The investigators at the Massachusetts Institute of Technology have shown the linear relationship between the log of the rate of loading and the reciprocal of absolute temperature of testing (Fig. 10).

If the service and composition of the steel which is being fabricated are such that transition temperature is higher than desired, consideration should be given to one of the supplementary practices which decreases the transition temperature; such as the use of quenched and tempered plate or following welding by either a local or a furnace stress-relief anneal.

In addition to the question of ductility in a weldability test, the fabricator is also interested in cracking sensitivity of the material which is being fabricated. Some correlation has been found between underbead

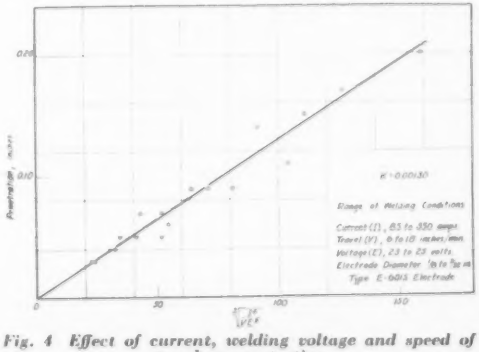


Fig. 4 Effect of current, welding voltage and speed of travel on penetration

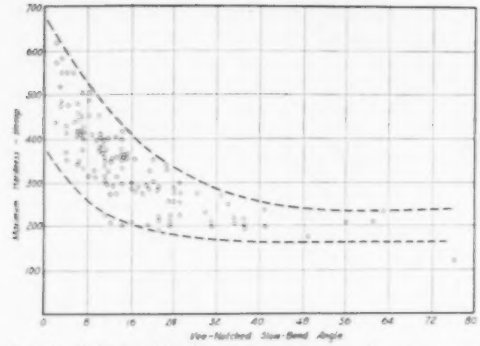


Fig. 5 Relationship between maximum hardness and bend angle (after Luther)

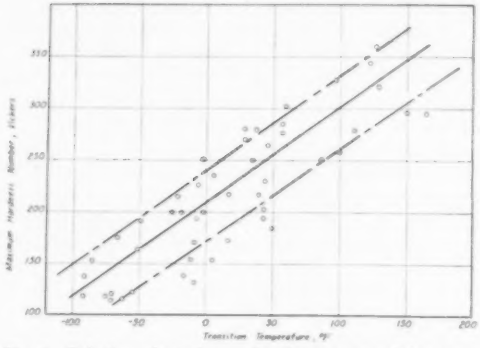


Fig. 6 Relation of maximum hardness to transition temperature

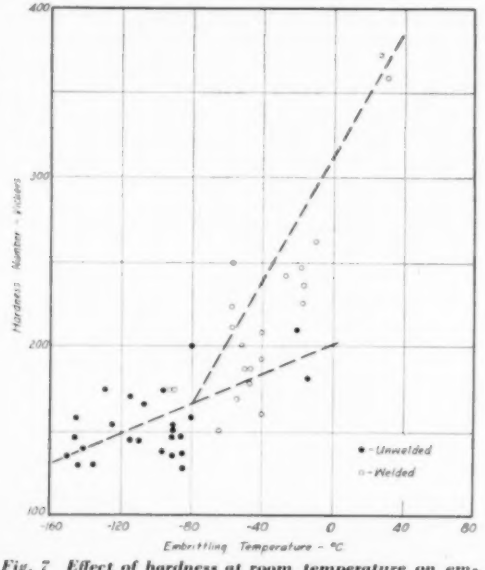


Fig. 7 Effect of hardness at room temperature on embrittling temperature (after Kinzel)

hardness, underbead crack sensitivity and bend ductility for carbon-manganese steels. There is a broad relationship between the hardness, crack sensitivity and bend angle factors to the chemical composition of the steel. As shown by Battelle in Fig. 11, all three of these factors are related to the carbon equivalent. These curves show that composition, including carbon, manganese and silicon, influence the crack sensitivity, hardness and bend angle at room temperature for this series of steels. It is possible that these test results will show almost a linear relationship with a factor based on the

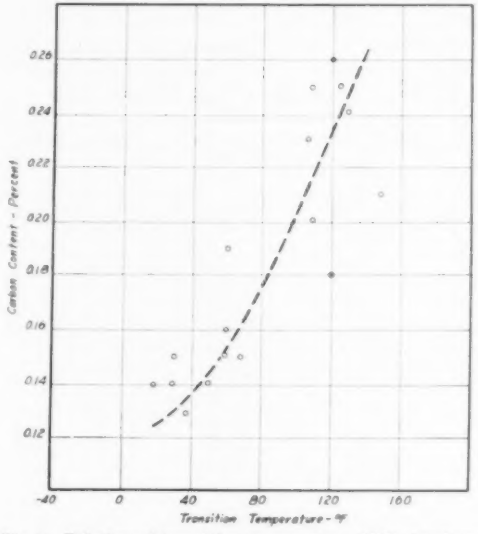
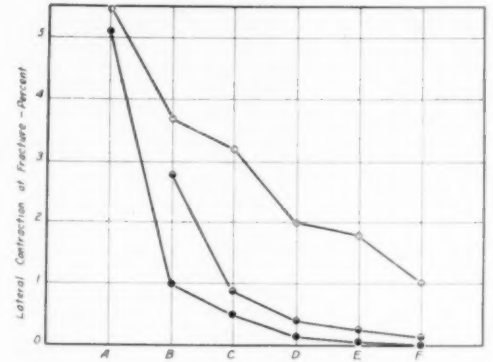


Fig. 8 Relation of transition temperature (50% shear) to carbon content (after Stout)



Specimen	Width	Notch Radius	Testing Temperature
A	3.0"	Unnotched	
B	1.5"	0.03"	○ = +60°C
C	1.5"	0.01"	
D	3.0"	0.03"	◒ = −100°C
E	3.0"	0.01"	
F	3.0"	0.01"	● = −140°C

Fig. 9 Effect of restraint on brittle fracture of test specimens with various notches using an 0.18% carbon plate (after Offenhauer and Koopman)

composition. From the British work, however, one must be cautioned regarding the use of additive composition factors for describing the relation of composition to transition temperature. They have indicated that the ratio of manganese to carbon may play an important part in the lowering of the transition temperature and suggest, for best performance, that the ratio of manganese to carbon be kept above three.

The work at the Massachusetts Institute of Technology and Rensselaer Polytechnic Institute, as well as that of the Union Carbide and Carbon Research Laboratories, Inc., has shown that some of the structures in the heat-affected zone are more effective in raising the transition temperature than other structures. It has been pointed out that as the width of the heat-affected zone increases, the transition temperature will be raised. For a given hardness level, the relationship between the width of the heat-affected zone and transition temperature for one steel has been shown to be linear (Fig. 12). This, then, leads one to use welding conditions which will give the narrowest heat-affected zone. The width of the heat-affected zone will be related to the welding technique, although no quantitative relationship can be pointed out. In general, as the travel is increased, the width of the heat-affected zone is decreased for a given energy input per linear inch of weld. There is need for additional information regarding the properties of the heat-affected zone and the methods of controlling its width. It is felt that a narrow heat-affected zone with a high maximum hardness will give better performance than a wide heat-affected zone with somewhat lower maximum hardness.

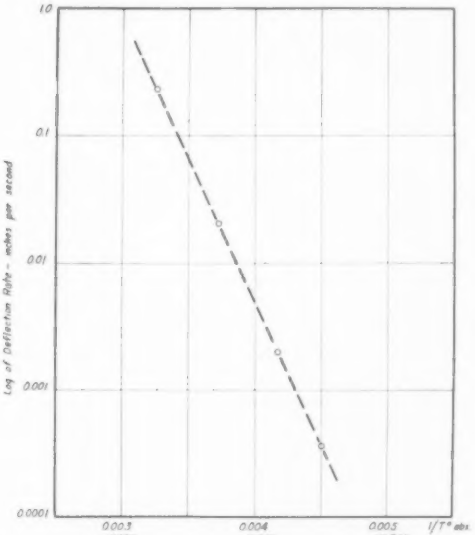


Fig. 10 Typical velocity—transformation temperature relationship (after MacGregor, Grossman and Shepler)

(1) Average of tests at room temperature, 150 and 225° F. preheats (heat input 16,000 watt-sec./in.). (2) Maximum hardness under 3-in. beads, 80° F. preheat (heat input 56,000 watt-sec./in.). (3) Bend angle for 5½-in. beads, 80° F. preheat (heat input 47,000 watt-sec./in.)

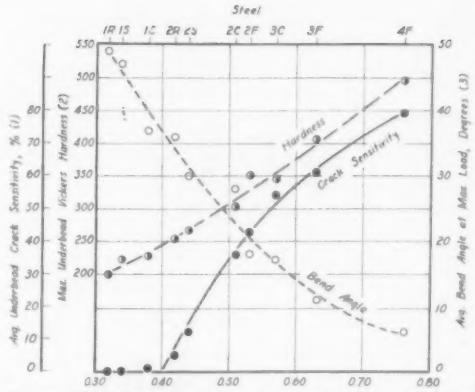


Fig. 11 Relation between steel composition and underbead hardness, crack sensitivity and notched-bead bend angle, for 1-in. plates of the commercial rolled carbon-manganese steels welded with Class E-6010 electrodes (after Voldrich and Harder)

The above comments apply to carbon and low-alloy steel. In the welding of medium-alloy steels, the problem is somewhat different. Preheat and postheat treatments are essential in order to avoid excessive hardening with loss of ductility in the heat-affected zone. The selection of postheat temperature should be such as to provide complete transformation of the heat-affected zone in the shortest possible time interval which usually results in bainitic structures.

X. SUMMARY

It may be stated again that we are interested in weldability because we want to produce a given design for a

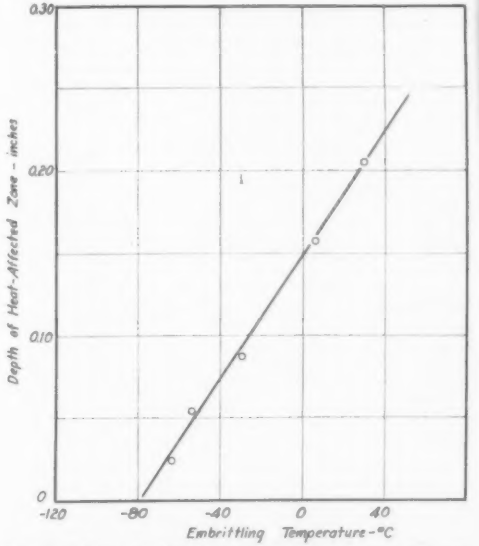


Fig. 12 Effect of depth of heat-affected zone on embrittling temperature

Steel No. 16: C = 0.16%, Mn = 0.45%, Si < 0.01%

given service by welding a given material by a given process.

A given design will fix the restraint which is present and the required thicknesses of material will control the cooling rates and cracking tendencies which will be encountered. The given service will control the properties required in the welded structure. These properties will vary, dependent upon whether the requirements of the service are stability (section), static loading or dynamic, which includes fatigue, slow- or ballistic-impact and creep. The given process which is used for fabricating any structure may be dictated by the service requirements or the design of the structure. Sometimes several methods might be used, although we are somewhat restricted in this choice. In the choice of material, a much greater latitude is possible. Materials of a wide variety of quality and composition are available, and from a weldability standpoint we should be able to select the material most suitable for the application.

In conclusion, the work of the Welding Research Council on Weldability has resulted in a number of practical developments which, together with the efforts of other laboratories, provide a working basis for evaluation of weldability.

Belgian Research Work*

THE Administrative Council of the Royal Scientific Institute, at its meeting October 4, 1948, approved support for the following research suggested by the Belgian Institute of Welding:

1. Study of a simple test to determine the resistance of a steel to brittle fracture.
2. Continuation of research on the measurement of residual stresses.

Part 1 above is a continuation of work begun by the Committee on Steel. A simple industrial test is sought which will allow quantitative estimation of tendency to brittle fracture.

As stated in an earlier issue, this research is being performed in collaboration with the Weldability Committee of the Netherlands Welding Society. The tests will be made exclusively on Belgian steels, particularly Steel A37HS, 1.58 in. thick, and Steel A37SC, 0.79 in. thick. The dynamic tests will be made in Holland while all the static tests will be made in Belgium. The majority of the Belgian tests will be made in the laboratory of Prof. Campus, University of Liege. A portion of the Belgian tests also will be made at the Materials Laboratory of the University of Ghent. The expenses for the Belgian tests are estimated to be 300,000 francs. The research should be completed this year.

Part 2 of the above program is the continuation of measurements made at the Materials Laboratory of the University of Ghent to determine residual stresses by resistance strain gages. The results of the preliminary work have been published in this magazine. The research is to be continued to show how residual stresses vary across the thickness of a plate, using the same principles as for the surface stresses. Since it is impossible to solve this problem theoretically, numerous measurements will be necessary on plate 0.39, 0.59 and 0.79 in. thick. The program also envisions the development of a simple apparatus for industrial use.

RESEARCHES ON THE STRENGTH OF SPOT WELDS

These researches are being undertaken by the Finn SA Electromécanique under the guidance of the Belgian Welding Institute and with the support of the Royal Institute. They are intended to complete some tests begun in 1936 to 1939 and are concerned with thin spot-welded sheets in two or three sheets. The sheets are 0.020, 0.031 and 0.039 in. thick in a cold-rolled steel having a tensile strength of 57,000 to 64,000 psi.

Object of the Research

1. To complete earlier work.
2. To determine the strength of thin spot-welded sheets in static tension, impact tension and fatigue.
3. To combine the new results with the earlier results.

Present Status of the Research

In the earlier work the minimum sheet thickness was 0.039 in. The tests showed that buckling lowered the compressive strength of spot-welded sheets. Tests were undertaken in static tension with a buckling coefficient of 0.72. Combining the old results with the new, we arrive at the following conclusions:

1. For sheets as thin as 0.020 in., the range of buckling coefficients that reduces the compressive strength is between 1 and 0.6.
2. Impact tension tests are being made but results are not yet available.
3. Fatigue tests will be undertaken as soon as a special fixture is built.

RESEARCHES ON LIGHT SPOT-WELDED TRUSSES

A. Tests. During 1948 static tests were made on the welded trusses. Three groups of pairs of trusses were tested. In two groups the gussets and truss members intersected. In the third group the truss members (bors) were eccentric with respect to the theoretical intersection, and there were no gussets.

B. Test Results. 1. In no instance was a spot weld broken. 2. For the three groups the maximum load was about four times the design load. Failure was by buckling of the compression flange. 3. Buckling occurred perpendicular to the plane of the trusses.

C. Tentative Conclusions. These tests show that it is perfectly possible, with a good welding machine, to make spot-welded trusses having the same safety factor under static loads as riveted, bolted or arc-welded trusses. However, some difficulties remain to be overcome in the practical production of spot-welded trusses. The assembly of the truss is time consuming and accounts for the small number of tests carried out in 1948. All spots to be welded must be carefully cleaned to avoid contamination of the electrodes. Satisfactory results have not yet been obtained without this preparation. Welding machine manufacturers should develop a means of avoiding the necessity for pickling or sanding. We understand that successful processes of this sort have been developed in the USA. Without such processes the cost of spot-welded trusses probably will be excessive. Furthermore, the use of a stationary welding machine makes it very inconvenient to weld the various spots. Portable spot welders would make the welding operation easier with fewer awkward manipulations.

Nevertheless, so far as the strength of spot-welded trusses are concerned, the results of our tests are very encouraging, and we anticipate further research on other types of trusses in accordance with the original program. There is also the problem of the fatigue strength of spot-welded trusses.

* Taken from *Rev. de la Soudure*, Brussels, No. 1, 1949.

Pearlitic Structure Effect on Brittle Transition Temperature

This preliminary study of the effect of pearlitic structure variations in low-carbon steel helps explain some of the differences in transition temperature of steels with the same chemical compositions. Material with small grain structure and with the finest pearlite spacing had the lowest transition temperatures

by Nicholas Grossman

Abstract

It has often been observed that steel plates rolled from the same heat or ingot may possess different impact properties. Since there is no appreciable variation in the chemistry of such steel, it is usually assumed that the microstructure is responsible for the variations in the mechanical properties. A plain, low-carbon steel plate was selected for tests to determine the effects of fineness of pearlite and grain size on the transition temperature of a specimen with a given geometry. It was found that the material with the small grain structure and with the finest pearlite spacing had the lowest transition temperature. The order and magnitude of the lowering of the transition temperature in proceeding from coarse to fine pearlite appeared to be about the same as that found in proceeding from the large to the small grains for this particular steel.

INTRODUCTION

IT IS common knowledge that low-carbon steels having identical chemical compositions may often possess differences in certain mechanical properties. This difference is not usually apparent in the ordinary tensile or hardness values but may be detected by the ability of the material to absorb shock loads. In the absence of the differences in chemical analyses, an obvious possible source predetermining this difference in behavior is the microstructure, which may be different due to mill practice, cooling rates, etc.

There are four variables in a given plain carbon steel with a pearlitic structure:

(*a*) the grain size,
(*b*) the spacing of the pearlitic lamellae,
(*c*) the amount of free ferrite and
(*d*) the amount of carbide in the pearlite.

These variables are not completely independent of each other and the range over which they can vary will be limited by the chemical composition and mill history of the steel. Previous investigators have studied the effects of microstructure on the various mechanical properties, and the findings reported in this paper are in line with their observations.[1–4] (These references were not selected to represent a complete review of the subject, but rather as a few typical examples.)

The aim of the present investigation was to measure the effect of different microstructures on a single mechanical property, which is most structure sensitive: the ability of the metal to absorb shock loads as reflected in the ductile-brittle transition temperature. Two of these variables were controlled: the grain size and the pearlite spacing. There was no attempt made to control the other two variables since that was beyond the scope of this preliminary study. The results reported in this paper are thus for the stated structural treatments and for the particular steel tested.

MATERIAL TEST

A plain, low-carbon, hot-rolled steel plate was supplied by Lehigh University.* This type of steel is extensively used in machine parts, welded structures, ship building and automotive industries.

PREPARATION OF SPECIMENS

Prior to the heat treatment of actual test bars, it was necessary to determine the limits between which the grain size and spacing in the pearlite could be varied and the degree to which desired combinations of these two variables could be reproduced. To determine the grain growth characteristics of this steel, samples

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* The mill history, chemical analyses and mechanical properties were furnished as follows (see also Table 1): purchased from Bethlehem Steel Co., Heat No. 45T538. The plates were obtained from the middle cuts of an ingot; A.S.T.M. Specification A7-46. Fine grain steel. No furnace kill. 650 lb. 50% FeSi added to ladle; no aluminum added to ladle. 1¼ lb. aluminum per ton of metal in mold. Ingot size 28¾ x 53 x 84 in. Sinkhead—big end up. Weight of heat about 130 tons. Obtained by pouring a sinkhead mold from a semikilled heat and kill in mold with aluminum for fine grain. Plate thickness is ¾ in. as-received.

($^3/_4$-in. cubes) were cut from the plate and heated to temperatures varying from 1500 to 2000° F. in 50° steps. Microscopic examination of these samples revealed that it was possible to produce only two grain sizes; a fine grain size with austenitizing temperatures between 1550 and 1750° F. and a coarse grain size over the range from 1850 to 2000° F. Within these two temperature ranges, only slight variations in grain size occurred. The interval between 1750 and 1850° F. represents the range over which the transition from fine to coarse grains took place. These results are normal for an inherently fine-grained, "killed" steel, such as the one used in this investigation. Representative photomicrographs are shown in Fig. 1.

As a result of this study, 1650° F. was chosen to produce the fine-grained test bars and 1900° F. for the coarse-grained.

A variation of pearlitic spacing was obtained by hot quenching a second series of cubes from the chosen austenitizing temperatures to a series of lower temperatures and isothermally transforming the austenite to pearlite at these temperatures. The hot quenching temperatures tried were 1050, 1100, 1200 and 1300° F. The transformation produced at 1300 °F. was fairly coarse pearlite, the spacing gradually becoming finer at the lower temperatures. Two holding times at the hot quenching temperatures were tried, 1 and 6 hr., but the longer time produced too much spheroidization of the carbide to be useful.

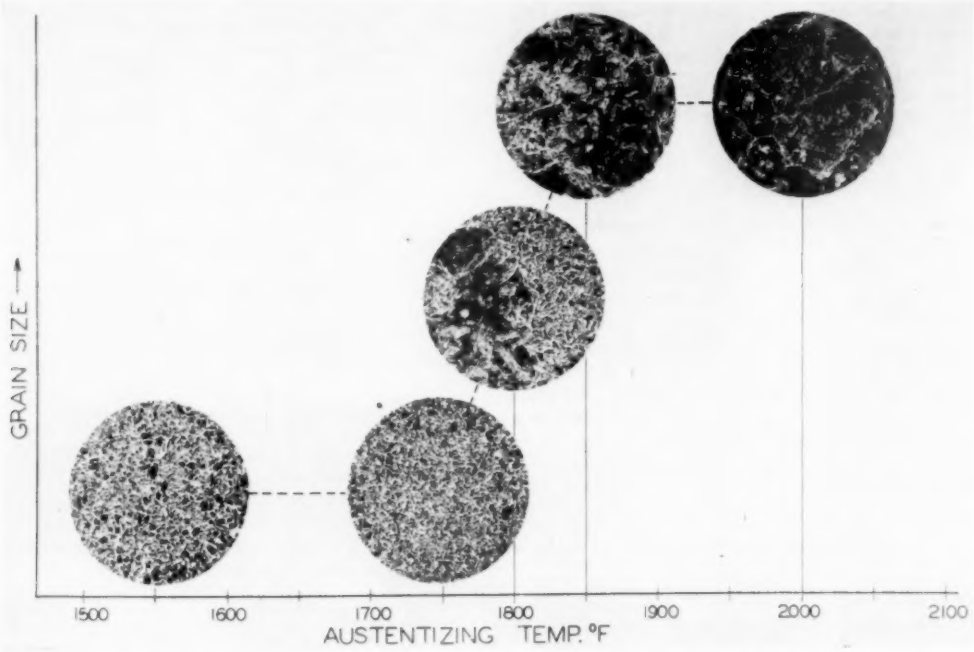
Table 1—Chemical Composition and Mechanical Properties (As-Received)

	C, %	*Mn*, %	*P*, %	*S*, %	*Si*, %	*Grain size*
Ladle	0.15	0.47	0.014	0.035	0.09	5-7
Check	0.17	0.48	0.012	0.039	0.09	

Yield point, psi.	Tensile strength, psi.	Elongation % in 8 in.
35,520	58,770	25.5

In the preparation of the test bars four heat-treating cycles were employed: (*a*) heated to 1900° F., held for 1 hr., furnace cooled to 1650° F., then hot quenched to 1300° F. and held for 1 hr. (large grain, coarse pearlite); (*b*) 1900° F., held for 1 hr. furnace cooled to 1650 °F., then hot quenched to 1100° F. and held for 1 hr. (large grain, fine pearlite); (*c*) 1650° F. held 1 hr., then hot quenched to 1300° F. and held for 1 hr. (small grain, coarse pearlite); (*d*) 1650° F. held for 1 hr., then hot quenched to 1100° F. and held there for 1 hr. (small grain, fine pearlite). The intermediate cooling step for the large grain specimens—i.e., furnace cooling from 1900 to 1650 ° F.—was employed to insure a variation in grain size while still maintaining identical cooling curves during the hot quenching operation; thus obtaining similar pearlitic spacing, regardless of grain size. The resulting photomicrographs are illustrated in Fig. 2.

Steel bars, 5 in. long and $^3/_4$ in. square, were heat treated to produce the microstructures described above. As a check on the heat treatments one bar in each batch was sectioned and the structures compared with those



Magnification 100 × (reduced $^1/_3$ in reproduction). Austenitizing time 1 hr. for $^3/_4$-in. samples. 2% Nital etch

Fig. 1 Grain size vs. austenitizing temperature. Low-carbon steel specimens tested

of the $^3/_4$-in. cubes; there was no detectable difference due to size effects.

Vee notches, $^3/_8$ in. deep with 0.01 in. radius and 45° included angle, were machined in the middle of the bars. The dimensions of the test specimens are given in Fig. 3.

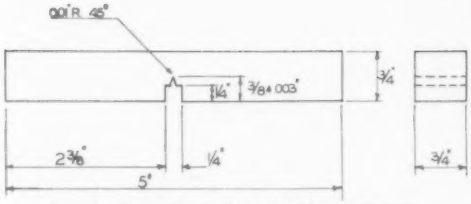


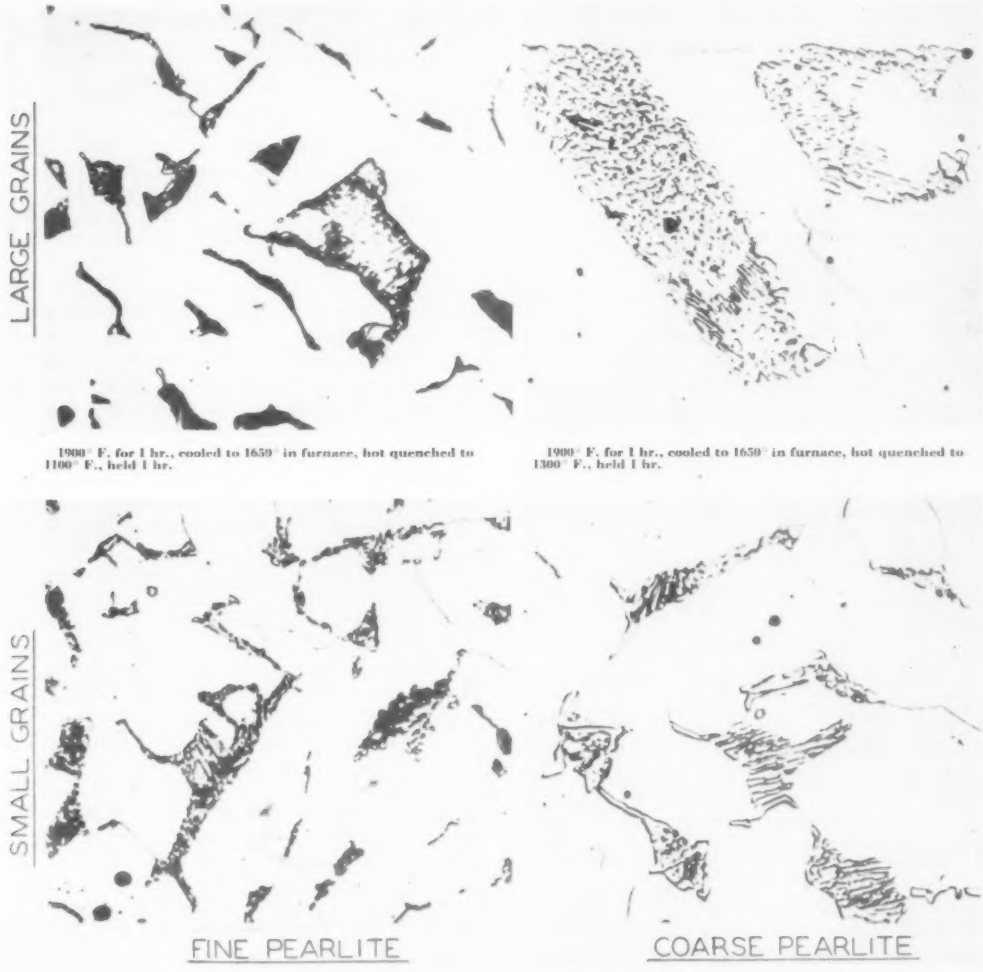
Fig. 3 Dimensions of notched bar specimen

APPARATUS AND TESTING PROCEDURE

A detailed description of the apparatus and the experimental technique has been given previously[6] and only a very brief outline of it is included here.

The testing equipment is designed to load a specimen in simple bending at a given uniform speed and temperature and to supply a load-deflection record of the test. AB-7, SR-4 electric strain gages connected in a bridge circuit are used to measure both the load and deflection. The integral parts of the apparatus include the loading machine with strain gages, the thermocouple and millivoltmeter, stop watch, electronic recorder and a still camera.

The transition temperature determined is that highest



1900° F. for 1 hr., cooled to 1650° in furnace, hot quenched to 1100° F., held 1 hr.

1900° F. for 1 hr., cooled to 1650° in furnace, hot quenched to 1300° F., held 1 hr.

1650° F. for 1 hr., hot quenched to 1100° F., held 1 hr.

1650° F. for 1 hr., hot quenched to 1300° F., held 1 hr.

Fig. 2 Grain sizes and pearlitic spacings of low-carbon steel specimens tested. Magnification 1500 ×

Table 2—Summary of Results

Specimen designation	Description	Transition temp., °F.	Deflection, in.	Time to fracture, sec.	Deflection rate, in. per sec.	1/Temperature, 1/°F. absolute
B	Large grain, coarse pearlite	− 55	0.0125	0.092	0.136	0.00247
		−133	0.0281	19.9	0.00141	0.00306
C	Large grain, fine pearlite	− 83	0.0272	0.132	0.206	0.00266
		−175	0.0459	24.1	0.00190	0.00349
D	Small grain, coarse pearlite	− 67	0.0232	0.092	0.252	0.00255
		−158	0.0255	16.6	0.00154	0.00330
E	Small grain, fine pearlite	−125	0.0309	0.132	0.234	0.00301
		−220	0.0433	23.1	0.00187	0.00417

temperature at a constant strain rate for which the material ceases all macroscopic ductile behavior as revealed by the load-deflection curve.

RESULTS

The results are summarized in Table 2. In addition, the logarithm of the deflection rate is plotted vs. the reciprocal of the absolute transition temperature (in degrees Fahrenheit) for the various structures tested, in Fig. 4. Only two deflection rates were chosen since it has been well established previously that the logarithm of the deflection rate is a linear function of the reciprocal of the absolute transition temperature for the metals of this type and in these temperature ranges.[5,6]

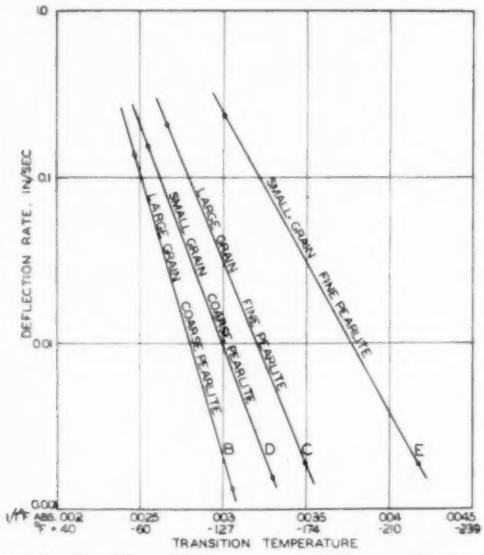


Fig. 4 Logarithm of deflection rate vs. reciprocal of absolute transition temperature for various microstructures tested

For more convenient form of comparison of the transition temperatures Table 3 lists the temperatures corresponding to 0.002 in. per second deflection rate; these values were taken from Fig. 4.

Table 3—Comparison of Transition Temperatures to 0.002 In. per Sec. Deflection Rate

Specimen designation	Description	Transition temp., °F.
B	Large grain, coarse pearlite	−130
C	Large grain, fine pearlite	−174
D	Small grain, coarse pearlite	−153
E	Small grain, fine pearlite	−219

DISCUSSION

The steel investigated exhibited two distinct grain sizes corresponding to two austenitizing temperature ranges. The pearlite was produced by an isothermal transformation so selected as to produce one closely packed fine pearlite, and a coarse, more dispersed lamellar structure.

The test results indicated (see Table 3) that in varying the structure from large grains to small grains, but keeping the same pearlite spacing, *the transition temperature decreased*; also in varying the fineness of pearlite for a given grain size the finer pearlite showed a *lower transition temperature*, than the coarse pearlite. It should be noted that the term "decrease in transition temperature" is synonymous in meaning with "greater ductility," or "higher impact energy," depending upon the method of evaluation employed.

As it is pointed out in the Introduction there are four variables involved in the microstructure of a low-carbon steel. In the present study no attempt was made to isolate all these variables and determine their effects on the brittle transition temperature. By using eutectoid steel specimens under suitable test conditions it may be possible to eliminate the effect of the variation in free ferrite inadvertently encountered in the present study.

CONCLUSION

The effects of grain size and fineness of pearlite on the brittle transition temperature of a plain, low-carbon steel were determined. It was found that: (1) the smaller grain structure has a lower transition temperature (as found previously by other investigators[1,4]) (i.e., it is more ductile than the one with the large grains); (2) the structure with the finer pearlite has a lower transition temperature than the coarse one. The order and magnitude in changing from coarse to fine

pearlite happen in this case to be about the same as going from large to small grains, for the steel tested.

Whether these changes in transition temperatures are entirely due to pearlite spacing and grain size or a combined effect of these factors as well as the amount of free ferrite and the carbide in the pearlite is not evident from this preliminary investigation. Thus the results reported yield quantitative data for the heat treatments in which grain size and pearlite spacing were controlled without any attempt to control the other variables.

ACKNOWLEDGMENTS

Dr. A. B. Kinzel and W. Spraragen suggested the investigation of this problem; they were most resourceful in procuring the necessary funds for the successful completion of this work. Prof. C. W. MacGregor guided and supervised this project. Prof. Morris Cohen advised the author on all metallurgical problems involved. J. J. Connelly carried out the heat treating of the test bars and metallographic measurements. The Metallurgy Department of Lehigh University supplied the steel plate tested. To all these the author wishes to express his sincere appreciation.

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The Porosity of Welds

The distinction between sulphur-sensitive and sulphur-insensitive welding electrodes is considered. This sensitiveness may be carried by alteration of the basic or the oxidizing character of the coating

by J. ter Berg and G. J. van Wijnen

INTRODUCTION

IT is known that external porosity in electric arc welding with coated welding electrodes is sometimes caused by sulphur. The sensitiveness of a certain welding electrode for this sulphur porosity depends upon the composition of this electrode. Therefore we may roughly make the following division into two groups:

(*a*) The sulphur-sensitive electrodes where a relatively slight S addition causes external porosity of the bead.

(*b*) The sulphur-insensitive electrodes where even an important S content does not cause external porosity.

We shall restrict ourselves to the consideration of Group *a*.

In preparing this article Mr. ter Berg became acquainted with an extensive and interesting article by G. E. Claussen in the January 1949 number of THE WELDING JOURNAL. The reader will observe that Claussen's results concerning sulphur are confirmed. For earlier reference to work on this subject the reader is referred to Philips Technical Review 7, p. 91, 1942. At the time this article was prepared the authors were connected with Philips' Glocilampenfabrieken, Eindhoven, Holland.

From the experiments described below we shall see that the degree of sulphur-sensitiveness is determined in the first place by the power to eliminate the sulphur from the liquid metal by the slag which forms itself during the welding. By relatively slight alteration of the coating's composition it will appear to be possible to obtain welds free from porosity, even with an important sulphur content of core wire and coating.

ALTERATION OF THE COATING

Two methods were applied to alter the coatings in order to obtain less sulphur-sensitive electrodes:

(*A*) The coating was made more basic in order to absorb more S in the slag.

(*B*) The oxidizing power of the coating was increased in order to get rid of the sulphur in the form of SO_2.

For the experiments electrodes were used with a core of rimmed steel with $\pm 0.1\%$ C and 0.4% Mn whereas the coating was applied by immersion. The plate material which was used was a St. 37 of the usual composition.

(*A*) *Increase of the Basic Character of the Coating*

To examine the influence of the coatings' basicity, a coating was used containing in addition to dolomite a quantity of quartz. By increasing the dolomite at the expense of the quartz, there were successively obtained three kinds of welding electrodes.

With these electrodes there were then made (the same as in the following experiments) various layers one upon the other on a strip, such as to obtain a convenient thickness of deposited metal. For analysis samples, material was only taken from the upper layers; hence the composition of the elemental material could have no influence on the analysis.

In Table 1 are given the coatings which are used and the analysis obtained.

Table 1

	a	*b*	*c*
Dolomite	5	15	25
Quartz	30	20	10
Iron oxide	25	25	25
Metal powder	25	25	25
Remainder + binder	15	15	15
S content of the deposited metal	0.090	0.085	0.079
S content of the slag	0.093	0.108	0.133
Distribution ratio	1.0	1.3	1.7

Furthermore the electrodes were "poisoned" for this test by addition of 1% FeS to the coating. As the table shows, the S content of the deposited metal decreases and seems to be absorbed, for a very great part, in the slag. As a consequence thereof we see that the distribution ratio which represents the proportion of the S percentages in slag and metal, increases.

When making welding experiments it appears now indeed that the S sensitiveness has decreased.

Figure 1 shows photographs of the three welding experiments which clearly demonstrate this course. The bead *a* shows besides great porosity a crack, the appearance of which is also in connection with the S content.

(*B*) *Increasing of the Oxidizing Power of the Coating*

The increasing of the oxidizing power also seemed, as supposed, to diminish the S sensitiveness.

Table 2 gives the employed welding electrode coatings and the analysis obtained.

The oxidizing power of the coating was obtained by substituting iron oxide for the iron powder.

Table 2

	d	*e*	*f*
Iron oxide	0	20	50
Iron powder	50	30	0
Quartz	20	20	20
Remainder + binder	20	20	20
S content of the metal	0.091	0.079	0.070
S content of the slag	0.098	0.090	0.078
Distribution ratio	1.1	1.1	1.1

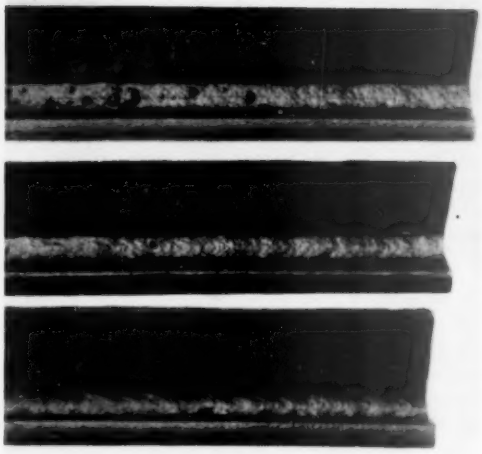


Figure 1
Type a (top); Type b (middle); Type c (bottom)

For this experiment the electrodes were also poisoned by introducing 1% FeS in the coating.

Again we see clearly a decrease of the S content in the deposited material whereas welding experiments gave also similar results as has been shown in Fig. 1†.

We may observe that, in opposition to the results quoted in (*A*), the S content of the slag decreases as a consequence of the fact that, because of the strongly oxidizing power of the coating, much of the sulphur disappears as SO_2. Indeed there can be shown an important quantity of sulphur-oxygen combinations in the escaping welding gases.

Hence, after having stated that by increase of the basic character or the oxidizing power of the coating the desulphurization of the metal and therewith the S insensitiveness is aided, it will be clear that the combination of these two means must be extremely effective.

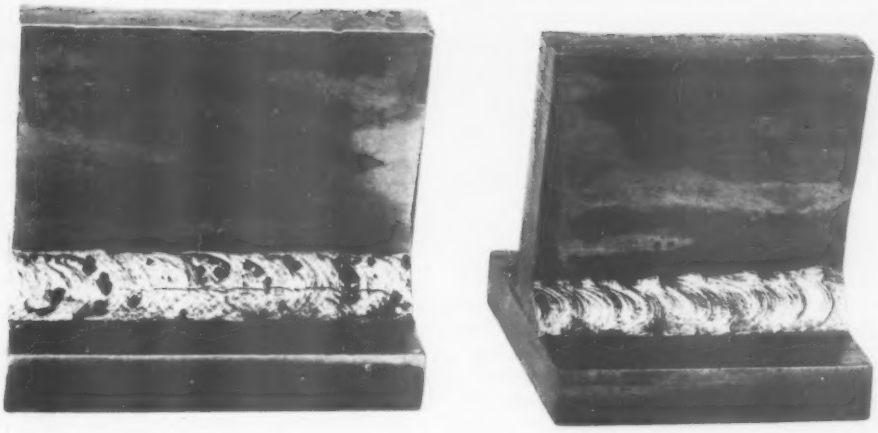
Indeed, this has been distinctly observed during a following series of experiments, of which the coating compositions and the attained sulphur contents are given in Table 3.

Table 3

	g	*h*	*i*
Iron oxide	0	20	60
Iron powder	60	40	0
Magnesite	15	15	15
Kaolin	15	15	15
Remainder + binder	10	10	10
S content of the metal	0.103	0.087	0.056
S content of the slag	0.080	0.143	0.162
Distribution ratio	0.8	1.6	2.9

The electrodes were again poisoned with 1% FeS in the coating.

† We draw the attention to the special shape of the little holes which are caused by sulphur, such as may be seen on the photographs. This shape is typical for S holes; the porosity caused by carbon which is to be described later, shows a totally different character.



Type b Type i

Figure 2

Coating *i* has besides its basic characteristics a strongly oxidizing power. The desulphurization is very strong and the distribution ratio mounts even to a value 2.9. It appears, as was to be expected when welding with this electrode, that no porosity shows itself, even when the plate material, the coating or the core wire contain a rather important quantity of sulphur.

Thus there are reproduced in Fig. 2 photographs of two fillet welds on free-cutting steel (S $\pm$ 0.3%).

The bead with a welding electrode of Type *b* shows again the typical sulphur holes whereas the other weld made with Type *i* is entirely sound.

Final Report Weld Stress Committee

E. Chapman, Chairman

THE Weld Stress Committee was authorized in February 1936, under the Chairmanship of Everett Chapman. The early instructions to the Committee were to study Weld Stresses, their causes, effects and the behavior of materials and welds under multiaxial stresses. In the light of present day knowledge it would be recognized that this assignment represented an almost impossible task for any single committee. Almost from the very beginning it was recognized that there was a serious overlapping in the scope of the Weld Stress Committee and a newly formed Weldability Committee. By arbitrary definition it was decided that the scope of the Weldability Committee would cover the effects of welding during the process of making and cooling of the weld down to ambient temperature. Problems relating to the behavior of the weld after it cooled, would fall within the scope of the Weld Stress Committee.

Some of the stress experts, even as far back as 1943, prevailed upon the Committee to break the problem down into two additional parts, namely, the study of the behavior of metals under multiaxial stresses, and the behavior of residual stresses in different structures under different service conditions.

Great credit is due to the Committee, and particularly its Chairman, in the very early days in an attempt to hold the Committee down to fundamental investigations rather than to attempt to pursue interesting by-

This report was prepared largely by W. Spraragen, Secretary Weld Stress Committee, with the cooperation of other members of the Committee.

paths in measuring residual stresses in specific structures. This stand was particularly difficult at that time because the Council received offers for special financing of specific applied investigations but was practically unable to raise any funds to carry out investigations of a more fundamental nature.

It should be realized that at that time the uppermost thought in the minds of experts was that residual stresses were directly responsible in one way or another for the occasional unexplained failures which took place in welded structures.

The impetus of the war brought about the necessity for tackling some of these problems on a much larger scale than was dreamed of in the early days of the formation of the Committee. It should be noted that even in these early days attempts were made to differentiate between the different types of residual stresses, namely, those that were local in nature due primarily to the heating and cooling of localized areas, and those which were due to actual connections of members in a given structure. The more local residual stresses were termed "residual stresses," and the more general residual stresses were termed "reaction stresses."

As a result of all of this discussion and much preliminary work the Committee formulated a program which was published in October 1944. The details of this program are reproduced herewith:

1. Residual Stresses Produced by Various Welding Procedures—Massachusetts Institute of Technology.
2. Behavior of Steel under Conditions of Multiaxial Stress and Repeated Loading—Illinois Institute of Technology.
3. High Speed Rotating Disk Project—Mechanical Engineering Dept., Massachusetts Institute of Technology.
4. Investigation on the Inherent Strength and Ductility of Steel under Conditions of Multiaxial Tension Present in Welded Structures—Case Institute of Technology.
5. Spherical Shells Subjected to Static Pressures—Pennsylvania State College.
6. Peening Program—American Bureau of Shipping.
7. Studies of the Flow, Fracture and Relaxation of Steels under Combined Stresses at High Temperatures—Westinghouse Electric Corp.

Inasmuch as this represents a final report of the Committee, it will be necessary to trace the disposition of each one of these proposals.

A comprehensive statement was prepared by some members of the Committee entitled "The Weld Stress Problem" which was published in the June 1945 issue of the *Welding Research Supplement*.

CONCLUSIONS

As a result of the work done by the Weld Stress Committee, by corresponding government agencies and by private individuals, the following general conclusions seem warranted at this time.

1. Stress corrosion specimens and the relaxation of weldments by machining indicate residual stress systems of considerable magnitude in welded structures. The relaxation of weld stresses by machining and its effect on stress corrosion can be demonstrated in the laboratory.

2. The detrimental effect as originally attributed to residual stresses in the useful life of a structure has not been established, although it is generally conceded that reaction stresses may progress a crack once initiated regardless of the cause—sometimes this elastic stored energy in a large structure may propagate a crack with explosive violence.

3. Stress relieving treatments, particularly thermal, have been proved to be beneficial in so far as the quality of a welded joint is concerned, and are still considered a necessity in many structures, as, for example, pressure vessels, machinery parts and the like. The beneficial effects are not primarily due to reduction of residual stresses, but rather to improvement of metallurgical structure, dimensional stability in machining operations and reduction in stress corrosion potentialities.

4. Preheating, peening, local stress relief and general stress relief, sequence of welding and similar devices, are known to be advantageous in preventing cracking on cooling, in minimizing and controlling distortion and in bringing about more desirable redistribution of stresses.

5. High concentrated stresses are always coincident with failure of a structure. They are usually multiaxial in nature and hence the great majority of investigations should be turned to the problem of plastic flow and fracture of metals under conditions that produce the gamut of failures from shear to cleavage.

6. It has been established by many investigators that design and workmanship which result in stress raisers and obstructions to the ductile behavior of metals are the most important elements in failure.

7. Next to design and workmanship, it is agreed that the notch sensitivity of steel at low temperatures is the most important consideration that must be taken into account in rigid welded monolithic field erected structures.

8. A concept of the inter-relation of rate of loading, temperature and degree of constraint for any particular steel and under any given set of conditions is now available. The importance of transition temperature of steel has been emphasized.

9. The desirability of avoiding metallurgical damage to steel during the fabricating process is generally conceded.

10. Many believe that the problems of stress corrosion and strain ageing are closely inter-related and are materially affected by the quality of steel, methods and procedure of welding.

11. Fracture where localized stresses are high will not take place if sufficient plastic flow can occur to sculpture the abrupt change of contour and strengthen the critical metal by work hardening.

SPECIFIC PROJECTS

(1) *Residual Welding Stresses—Massachusetts Institute of Technology*

The original program of the M.I.T. group of investigators was started under the University Research Committee. It was concerned with the development of the X-ray diffraction technique for measuring residual welding stresses and the change in the residual welding stress pattern with different types of stresses. In the first program, the X-ray diffraction method was perfected for measuring surface stresses. A stress pattern was induced by heating a test specimen in the jaws of a spot welding machine. Upon application of tension load the pattern changed and peak residual stresses were ironed out as application of load brought the combined residual and load stresses above the plastic flow point of the metal. The same thing happened in fatigue where the first few cycles of stress reduced the residual stresses. Specimens with and without residual stresses, therefore, behaved almost identically in fatigue loads. The investigation was enlarged to obtain a clear picture of the residual stress situation both at the surface and interior of weldments prepared under controlled conditions of welding. A number of very valuable papers were published in the *Welding Research Supplement* as the result of this research work. A list of these reports is as follows:

"X-ray Methods of Studying Stress Relief in Welds," by J. T. Norton, October 1937, pp. 19–22.

"Stress Measurements in Weldments by X-rays," by J. T. Norton and Blake M. Loring, June 1941, pp. 284-s to 287-s.

"An Investigation of the Behavior of Residual Stresses under External Load and Their Effect upon Safety," by J. T. Norton and D. Rosenthal, February 1943, pp. 63-s to 78-s.

"A Method of Measuring Triaxial Residual Stress in Plates," by D. Rosenthal and J. T. Norton, May 1945, pp. 295-s to 307-s.

"X-ray Diffraction Study of Notch Bend Test," by J. T. Norton, D. Rosenthal and S. B. Maloof, May 1946, pp. 269-s to 276-s.

"Critical Review of Weld Stress Problem," by J. T. Norton and D. Rosenthal, May 1946, pp. 277-s to 282-s.

"X-ray Diffraction Study of the Effect of Residual Compression on the Fatigue of Notched Specimens," by J. T. Norton, D. Rosenthal and S. B. Maloof, November 1946, pp. 729-s to 735-s.

(2) *Behavior of Steel under Conditions of Multiaxial Stress and Repeated Loading—Illinois Institute of Technology*

The Committee designed and built a machine for producing biaxial fatigue stresses in hollow tubes. As a result of this investigation it was demonstrated that the behavior of steel under biaxial fatigue stresses was not much different than under uniaxial fatigue conditions, and that residual welding stresses did not materially affect the results. Anisotropy is the major factor in lowering the endurance limit some 15% when stresses in the transverse direction are predominant. The fatigue strength of welded material is about 15% less than for unwelded material.

A report was published as follows: "Biaxial Fatigue Strength of Low-Carbon Steels," by George K. Morikawa and LeVan Griffis, March 1945, pp. 167-s to 174-s.

(3) *High Speed Rotating Disk Project—Massachusetts Institute of Technology*

One of the greatest problems confronting investigations in this field is to obtain an inexpensive specimen for producing biaxial stresses. In the past such specimens usually were either hemispheres or tubes. The Weld Stress Committee designed a high speed rotating disk for studying plates up to 2 in. in thickness and 27 in. in diameter. This would enable the Committee to produce biaxial tension in thick plates with and without residual stresses, and by notch effects to also produce a considerable amount of triaxiality. The project was delayed during the war because of lack of materials. After the war the project was continued and an actual rotating spinning disk was developed to the point of fracture. A description of the machine and results of several specimens are described in the following paper: "Developments in High-Speed Rotating Disk Research at M.I.T.," by C. W. MacGregor and W. D. Tierney, June 1948 *Supplement*, pp. 303-s to 309-s.

Inasmuch as the Committee has been in the process of liquidation for the past couple of years it was decided to transfer this project to the Ship Structure Committee. This Committee represents three governmental agencies, namely, U. S. Navy, U. S. Maritime Commission and U. S. Coast Guard; also the American Bureau of Shipping. This Committee was badly in need of this type of facilities for examining notch sensitivity of steel at various temperatures. Work will be continued and made available to the Council. This apparatus will be useful to any committee which is organized to study the plastic flow and fracture of metals at a later date.

(4) *Investigation of the Inherent Strength and Ductility of Steel under Conditions of Multiaxial Tension in Welded Structures—Case Institute of Technology*

To evaluate the strength and ductility of a weld it is necessary to determine the properties of its component parts, and the effect of welding on the assembly separately. This investigation showed that two zones of low ductility may be present in manually welded plates, one at the weld center line, and a second in the subcritically heated parent metal. The latter point also indicated a relatively higher transition temperature. A stress re-

lieving treatment at 1150° restored the ductility in these brittle zones. Published papers are:

"Distribution of Strength and Ductility in Welded Steel Plate as Revealed by the Static Notch Bar Tensile Test," by W. F. Brown, Jr., L. J. Ebert and George Sachs, October 1947, pp. 545-s to 554-s.

"Effects of Section Size on Static Strength of Mild Steel Plates," by W. F. Brown, Jr., J. D. Lubahn and L. J. Ebert, October 1947, pp. 554-s to 559-s.

(5) *Spherical Shells Subjected to Static Pressures—Pennsylvania State College*

The purpose of this investigation was to determine the mechanical properties of a semikilled pressure vessel steel, of more typical thickness dimensions, when stressed in biaxial tension at subnormal temperatures. For this purpose spherical shell specimens were subjected to internal pressure up to rupture. The mechanical properties determined include the plastic stress-strain relations, yield, ultimate and fracture strengths and ductility. In these tests a combined state of stress was produced consisting essentially of biaxial tensions of equal magnitude with a small compression caused by the internal pressure in the thickness direction.

A comparison of the true plastic stress-strain relation with the theoretical values shows that for the room temperature test the Generalized St. Venant Theory gives a good approximation of the test results. The yield strength, and the true and nominal ultimate strengths in the room temperature test are in approximate agreement with the Shear Stress Theory of strength if the value of the internal pressure is taken as the stress in the thickness direction. The nominal ultimate strength in this test was about 87% of the tensile strength of the material and about 96% of the value that would be predicted using the Shear Stress Theory.

The ductility values based on wall thickness measurements for the room temperature test were found to be in good agreement with the Generalized Theory. Decreases in temperature showed a reduction but not a regular trend in combined stress ductility values. The fractures were of the cleavage type at the lower temperatures but real brittleness was not encountered as long as the fractures did not originate in the region of a joint.

The results of these tests show, however, that a notch effect such as may result from defective workmanship in a joint can be the nucleus for initiating a very brittle fracture under biaxial stresses at low temperatures. Whether such a notch or flaw is a greater potential hazard than it would be under uniaxial stress in plates of similar size at these temperatures has not been sufficiently determined. This report was published in the Dec. 1948 issue of the *Welding Research Supplement*, pp. 593–607.

(6) *Peening—American Bureau of Shipping*

The main objective of this investigation was to develop a scientific procedure whereby peening could be definitely controlled, optimum conditions such as size and shape of peening tool, rate of travel and temperatures for peening determined, and to prove, or disprove, the validity of Code requirements in connection with the elimination of peening in the first and last layers. A hunt for a suitable laboratory extended over a period of several years and the Committee is happy to report that the American Bureau of Shipping has agreed to undertake the work. Steel has been ordered, a program laid out, and the investigational work will be shortly started. It is planned to continue the work of this Subcommittee after the main Weld Stress Committee is discharged.

(7) *Studies of the Flow, Fracture and Relaxation of Steels under Combined Stresses at High Temperatures*

Proposals along these lines were made by a prominent laboratory connected with an industrial company, and work along these lines will be carried out by that company.

OTHER ACTIVITIES OF THE COMMITTEE

Probably the greatest single accomplishment of the Weld Stress Committee was the concentration of thought by the experts of that Committee on the general problem of Weld Stresses and the Flow and Fracture of Metals in rigid monolithic welded structures. It is expected that some day, either under the auspices of the Welding Research Council or under other auspices, programs will be started in the flow and fracture field. As a beginning in this direction the Council has published two comprehensive digests of available information on this subject, one carried out under its own auspices by Dr. J. H. Hollomon entitled, "The Problem of Fracture," published in the September 1946 issue of the *Welding Research Supplement*, pp. 534–583, and the other by Maxwell Gensamer, Edward Saibel and John T. Ransom, under the auspices of the Navy Department, entitled "Report on the Fracture of Metals," published in the August 1947 issue of the *Supplement*, pp. 443–484.

Great credit is due to the many able investigators participating in the work of the Weld Stress Committee, and to the large number of committee members who gave their time and thought to the subject. Credit is also due to the financial contributors, a partial list of whom is as follows:

American Bureau of Shipping, American Iron and Steel Institute, Babcock and Wilcox Co., Chicago Bridge and Iron Co., Climax Molybdenum Co., Combustion Engineering Co., Griscom Russell Co., General Electric Co., New York Shipbuilding Co., Pullman Standard Car Manufacturing Co., Southern California Gas Co., and Todd Shipyards Corp.

Welded Joints in Thick Aluminum Plates

Argon-shielded arc welds in 1 1/2 in. thick 3S plate can be produced equal in tensile strength to parent metal even at extremely low temperatures. In welding higher strength, heat-treated alloys further research is needed

by C. B. Voldrich

Abstract

Tests of argon-arc welds in 1 1/2-in.-thick 3S plate showed that the welded joints had tensile strength properties equal to those of the parent material, even at liquid-nitrogen temperature (−320 F.). Tests of argon-arc welds in several types of high-strength, heat-treatable aluminum alloys, in plates 1 1/2 in. thick, showed that sound welds can be made with some of the available filler metal alloys. In certain cases, these welds have tensile strengths approaching those of the heat-treated parent material, but it is indicated that additional work will be required to produce weld metals with satisfactory ductility and response to heat treatment. This may depend on improved welding technique or on the development of better filler metals.

The influence of the welding heat on the properties of the heat-treated aluminum-alloy plates, in regions remote from the weld area, is also discussed.

INTRODUCTION

UNTIL a few years ago, the welding of thick plates and shapes of aluminum into major structures was a rarity. However, wartime experiences and demands, new developments in chemical and mechanical engineering, the increasing availability of aluminum-alloy plates and shapes in thicker and stronger sections, and the advent of some new welding techniques, have raised the welding of thick aluminum sections from the specialty class to the level of the practicable, desirable and oftentimes indispensable engineering procedure. The designer of aluminum structures now deals with section thicknesses of 1, 2 and even 6 in.; he looks forward to weld-joint tensile strengths of 30,000, 50,000 and even 70,000 psi., and to joint efficiencies of 80% or more; he designs thick-section aluminum weldments for pipe lines, bridge trusses, pressure vessels, airplane wings, vehicle and machinery frames and the like, whenever the engineering and economic considerations call for special attention to factors such as weight saving, structural stability, corrosion resistance to certain media, heat-transfer characteristics and low-temperature strength properties.

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This paper was presented at the Petroleum Conference of the American Society of Mechanical Engineers in Amarillo, Tex., on Oct. 5, 1948 and at the Western Metals Congress, Los Angeles, April 13, 1949.

At Battelle Memorial Institute, research on this general problem began in 1946 with a survey, for the Army Ordnance Department, on the industrial status of thick aluminum welding. The results of this survey* showed, not unexpectedly, that in 1946 there was very little fabrication by welding of aluminum plating thicker than 3/4 in., and no information on the weldability and weld-joint strength of the heat-treatable alloys, except for thin sheet and plate. Following this survey, the Ordnance Department authorized a research investigation at Battelle on the welding of aluminum-alloy plates in thicknesses 1 in. and over, which is still in progress.

At about the same time, new developments in synthetic gasoline manufacture, and in the design of oxygen-manufacturing equipment to be operated as a part of the synthetic fuel process, brought about the need for more extensive research on the welding of aluminum plating for thick-walled pressure vessels, heat exchangers and similar equipment. Partially as a consequence of these developments, two additional projects on aluminum welding were begun at Battelle: one for the Stacey Brothers Gas Construction Co., on welding techniques and the properties of welded joints in thick aluminum plates; and the other for the Air Reduction Sales Co., on the development of new welding processes for thick aluminum plating.

This paper deals with the results of some of the work conducted on the three projects, chiefly that concerning the strength properties of welds in thick plates. After a description of the alloys tested, and of the welding techniques used, the strength data are presented in two sections: (1) tests of welded joints for low-temperature service, and (2) tests of welds in high-strength alloys.

The author appreciates the courtesy of the U. S. Army Ordnance Dept., the Stacey Brothers Gas Construction Co., the Air Reduction Sales Co. and Battelle Memorial Institute in permitting the preparation of this account of the research, and wishes also to acknowledge the contributions of R. D. Williams, P. J. Rieppel, C. M. Craighead, L. K. Birinyi, H. B. Cary, A. R. Meyer, P.

* "Survey on Welding of Aluminum and Magnesium," Report No. PB-78712, Office of Technical Services, Department of Commerce, Washington 25, D. C.

L. Mirolo and others of the Battelle staff who participated in the work.

THE MATERIALS TESTED

Aluminum Plates

The base materials used in the welding tests were $1^1/_2$- and 2-in. rolled plates of the strain-hardening alloy 3S and the heat-treatable alloys 24S, 61S and 75S.*

The 3S plate is available in several tempers (i.e., conditions of hardness, strength and ductility), which are produced by suitable combinations of cold working and annealing during the rolling of the plate. In very thick sections, only a limited amount of cold rolling can be done, and the thick plates are therefore normally available only in the lower strength ranges. When strain-hardened 3S plate is heated to about 600° F., it reverts to the annealed, low-strength condition. A slight amount of annealing will occur even at lower temperatures, down to about 400° F. Since in welding there is a base-metal zone, adjacent to the weld, which is heated to 400° F. and above, the strength of this zone is less than that of the prime plate. Consequently, the design strength of most 3S weldments is based on the properties of the material in the annealed condition (3S-O).

The high-strength, heat-treatable alloys, such as 24S, 61S and 75S, derive their strength properties from the presence, in the aluminum matrix, of hardening constituents such as copper, magnesium, silicon and zinc, and compounds of these elements with each other and with aluminum. The principal improvement in strength and hardness is obtained by heat treating the aluminum alloy in a manner which produces the optimum particle size and distribution of the hardening constituents. In some of these alloys, an additional strengthening may be produced by an addition of cold working during the heat-treating process. The final stage in the heat treatment is an aging at low temperature, ranging from room temperature to about 375° F. Subsequent heating to higher temperatures will cause "overaging" or even annealing, with a decrease in strength. In welding, such higher temperatures obtain, but usually for a relatively short time. Consequently, the overaging in the base-metal zone adjacent to the weld may not be very great, particularly in those alloys whose optimum aging temperature is on the high side, and whose aging response is sluggish.

The properties of the heat-affected zone in the high-strength alloys may be restored by a suitable heat treatment of the weldment. However, most of the filler metals now available produce weld metals which, in either the as-welded or heat-treated condition, are not so strong as the base metal, and whose ductility is low at the higher strength levels. Consequently, the weld-joint strength is governed by the strength of the weld metal, and the problem of the heat-affected zone in the base metal will become important only when weld metals are obtained which match the base metal in strength.*

* All designations of aluminum alloys are in accordance with the 1946 nomenclature of the Aluminum Company of America, unless otherwise indicated.

Table 1—Nominal Chemical Composition of Aluminum Alloys*

Alloy	Composition, %						
	Cu	*Mg*	*Mn*	*Cr*	*Si*	*Zn*	*Al*
2S	....	..	..	....	..	..	99+
3S	....	..	1.2	....	..	..	Rem.
24S	4.5	1.5	0.6	....	..	..	Rem.
61S	0.25	1.0	..	0.25	0.6	..	Rem.
75S	1.6	2.5	..	0.3	..	5.6	Rem.

* Data from "Alcoa Aluminum and Its Alloys," 1947.

Table 1 gives the nominal chemical compositions of the types of aluminum plate investigated, and Table 2 shows the strength properties of the $1^1/_2$-in. plates actually used in the tests. The 2S and 3S plates were in a cold-worked condition, though not to the hardness and strength attainable in thinner plates and sheets. The 61S and 75S alloys were available in two conditions—Condition W, plates quenched from the solution-treating temperature but not subsequently aged; and Condition T, plates solution heat treated, quenched, and then aged at the optimum temperature. The 24S-T plate was available only in the aged condition.

The heat-treatable alloy plates were fabricated specially for the welding research work, and for research at other laboratories on the strength properties of thick plates. Since the processing of these plates did not conform to that used for the commercial product, this difference has been indicated by the use of the prefix "E" in all designations of these alloys.

Filler Metals

The welding rods used in the preparation of the test specimens were plain aluminum, 2S; the 5% silicon alloy, 43S, which at present is the most extensively used filler metal; a 10% silicon–4% copper alloy, 716, which heretofore has been employed principally as a brazing alloy; and the more complex 24S, 61S and 75S alloys.

* This does not hold for weld joints in thin sheet and plate, in which a full weld bead or reinforcement is retained, and whose weld metal is entirely or largely the melted base metal.

Table 2—Strength of $1^1/_2$ In.-Thick Rolled Plates of Various Aluminum Alloys*

Alloy†	*Yield strength, psi.*	*Ultimate tensile strength, psi.*	*Elongation 8 in., %*
2S	8,000	14,000	30
3S	9,000	18,000	28
E61SW	18,000	35,000	25
E61ST	38,000	45,000	16
E24ST	47,000	70,000	17
E75SW	54,000	78,000	13
E75ST	72,000	82,000	9

* Tension tests of full-thickness unwelded flat-bar specimens.
† W temper—solution heat treated only (quenched condition).
T temper—solution heat treated and precipitation heat treated or aged. Prefix "E" denotes specially rolled plate.

The 2S filler metal was chosen for the preparation of the welds in 3S plate because the design requirements called for the maximum possible ductility in the weld joint. The 43S alloy was considered for this work, because it has better welding characteristics than 2S and produces stronger welds; but it was not used on account of its relatively lower ductility.

The initial experiments with the heat-treatable alloys were made using 43S and 716 filler metals, because these were the only commercially available wires, and because considerable welding of the higher strength alloys, in thinner sections, was being done with the 43S metal. Prior experience indicated, however, that these filler metals probably would not produce welds with high strength and ductility, except perhaps after heat treatment. Additional weld specimens were therefore made using filler metals of the same composition as the base plates. While reports of other investigators indicated that these filler metals did not have the most favorable welding characteristics, chiefly as regards their tendency toward cracking, it was felt that the results of such tests would form a good basis for subsequent research on other filler-metal compositions.

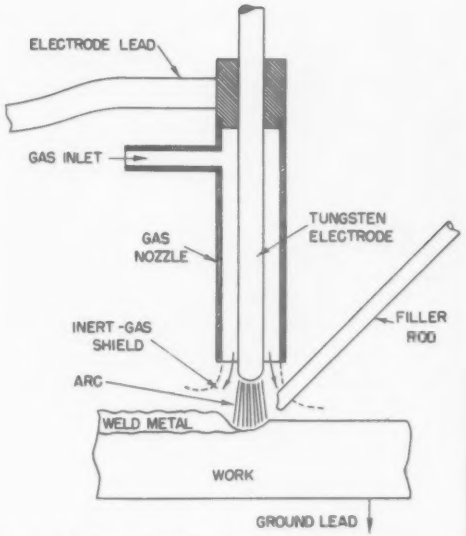

Fig. 1 Schematic diagram of torch for inert-gas tungsten-arc welding

THE WELDING METHOD

For aluminum plates thicker than about $^1/_2$ in., the number of practicable welding processes narrows down to three—metal-arc welding with flux-covered aluminum electrodes, carbon-arc welding with a separate filler rod and flux, and tungsten-arc welding in an inert-gas shield with a separate filler rod and no flux.

At the start of the Battelle investigations, all three processes were tried. While each method showed certain advantages, the indications were that, considering factors such as ease of training welding operators, ease of welding, visibility of the work, cleaning of the finished weld, and quality of the weld metal, the inert-gas-shielded tungsten-arc process was most suitable for thick aluminum welding. Consequently, the tungsten-arc method has been used in most of the more recent research, and all of the weld specimens described in this report were made by that process.

The Argon-Arc Welding Process

Figure 1 shows the essentials of the inert-gas-shielded tungsten-arc process (hereafter called the argon-arc process) used in the Battelle investigations. The work and the filler rod are melted together under an electric arc between the work and a tungsten electrode, with the arc, electrode tip and molten weld pool shielded from the air by a gentle stream of helium or argon issuing from the gas nozzle. The tungsten electrode and gas nozzle may be in the form of a "torch" for manual welding, or may be attached to a carriage for mechanized welding. For smaller work which requires currents less than about 200 amp., direct current (electrode positive) is generally used; but for thicker plates, which require welding currents of 300 to 600 amp., it is necessary to use alternating current to avoid overheating and melting of the tungsten electrode. No chemical flux is used on either the workpieces or the filler rod, but it is desirable that the surfaces of both the rod and the weld joint be well cleaned before welding begins.

To aid in starting the arc, and to improve arc stability during welding, a high-voltage, high-frequency current may be superimposed on the welding current. Automatic devices are now available which turn on the high-frequency current only when the tungsten electrode is first touched to the work, or the arc is momentarily extinguished during welding.

When alternating current is used in the argon-arc welding of aluminum, there is a partial rectification of the current which is reputed to have an undesirable influence on the ease of welding and on weld quality, and which may cause an overloading of the welding transformer. This rectification may be eliminated or reduced by various means such as capacitors or direct-current storage batteries in the welding circuit, or it may be offset by using transformers with suitable characteristics, including high open-circuit voltage.

Figure 2 shows the manual argon-arc welding of a single-vee joint in thick 3S plates.

Preheat Requirements

One of the essential requirements for the argon-arc welding of thick aluminum plates is that they be preheated either locally in the region of welding, or over the entire plate area, and that this temperature be maintained during the deposition of all the beads or layers in the weld joint. This is not done to prevent undesirable heat effects in the parent plate (as is the

Fig. 2 Argon-Arc welding of thick aluminum plates

case in the welding of air-hardening alloy steels); the purpose is to prevent chilling of the weld pool, which occurs in aluminum very readily because of its high heat conductivity. If the plates are too cold, the progress of welding is very slow, and it is difficult to maintain the proper weld-metal flow and fusing action between the molten metal and the side walls of the joint.

The preheats usually recommended for thick aluminum plates vary from 200 to 500° F., depending on the welding process used and the amount of heating energy available at the arc. In the present tests, preheats of 300 to 400° F. were found satisfactory, and conformed to the present practice in many production operations. The values 300 and 400° F. reported are nominal ones, which represent the average temperature over the entire weld assembly during the 2 or 3 hr. required to make a complete weld. Near the weld joint, the plate temperature increased for a short while to 500 or 600° F. as each weld bead was deposited. Between weld beads, sufficient time was allowed for the weldment to cool down to the average preheat temperature.

STRENGTH PROPERTIES OF WELDED JOINTS FOR LOW-TEMPERATURE SERVICE

One of the important recent applications of thick-plate aluminum weldments is in the construction of pressure vessels, containers, heat exchangers, piping, etc., for oxygen-manufacturing plants. Most of this equipment is for service at relatively low pressures, at temperatures varying cyclically from room temperature to that of liquid nitrogen (−320° F.). Because aluminum is among the metals which do not lose strength and ductility at low temperatures, and for various other reasons, it was selected as the material to be used in the construction of oxygen-processing equipment. Since the most efficient designs of this equipment called for structures whose major parts are joined by welding, it was necessary to determine (1) if the thick plates required could be welded, (2) which among the available welding processes and techniques were most suitable for this work and (3) the mechanical properties of the weld metals and weld joints at the various service temperatures.

The aluminum-manganese alloy 3S was chosen as the plate material, and plain aluminum, 2S, as the filler metal for welding, because experience with thinner materials had shown that satisfactory weld joints with very good ductility, although at a relatively low yield strength, could be produced with these metals. Furthermore, with these common alloys there was no need for concern about the effect of the welding heat on the strength of the plate, since the designs were to be based on the strength of the 3S plate in the full-annealed condition.

(Subsequent research indicates that some of the higher strength alloys, notably 61S, can probably be used for this class of weldment. However, very little is yet known about the low-temperature properties of welds in 61S, and lower ductility in the weld metal has to be accepted. It is not practicable to use the low-strength weld metal, 2S, in the higher strength alloys because the joint efficiency would be very low; higher strength alloys such as 43S and 71S are used as filler metals, and these, while having a higher yield strength than 2S, have lower ductilities. It is probable that, as experience with the thick-walled equipment is accumulated, the somewhat lower ductilities of the alloy weld metals will be acceptable.)

Preparation of Weld Specimens

Thick plates of 3S aluminum alloy were welded using

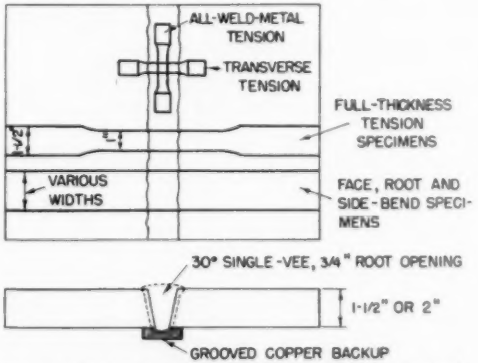

Fig. 3 Details of tension and bend specimens from single-vee weld joint in thick aluminum-alloy plates

the joint design shown in Fig. 3. This design was chosen as representative of anticipated conditions in the shop and field where certain joints would be accessible from one side only. Figure 4 shows a cross section of a typical single-vee multiple-bead welded joint in thick 38 plate.

The size of the welded plates varied from 8 x 24 in. to 30 x 48 in., depending on the number and type of test specimens required. The plates were clamped firmly to the steel frame of a welding table, with asbestos sheets between the plates and the table to prevent unequal localized chilling. All welding was done in the flat (downhand) position, with the following welding conditions:

Welding torch—manual, 800-amp. capacity, with $^5/_{16}$-in.-diameter tungsten electrode and a gas nozzle with an inside diameter of $^5/_8$ in.
Shielding gas—welding-grade argon, at a flow of about 1.2 cu. ft. per minute.
Source of welding current—two 500-amp. a.-c. transformers connected in parallel (80 v., open circuit), with a separate high-frequency current unit to aid in arc starting and stabilization.
Welding current—450 to 550 amp.
Filler metal—$^5/_{16}$-in.-diameter 2S wire
Preheat of plates—approximately 300° F.

In the welding of these plates, direct-current storage batteries in series with the welding circuit were used to reduce rectification of the alternating welding current. At this stage in the work, it appeared desirable to use positive means to prevent rectification, to assist in securing good welding conditions and weld quality. In the later tests with high-strength alloys, when the welding operators had gained more experience in the handling of thick aluminum plates, it was possible to make good welds, with no objectionable arc instability or oxide-film interference during welding, without the use of the balancing storage batteries.

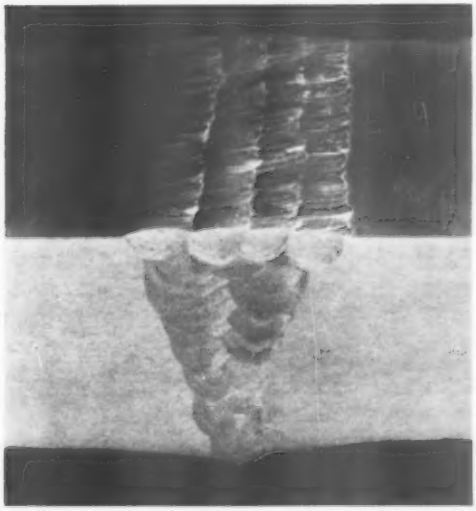

Fig. 4 Cross section of single-vee weld joint in 2-in. 38 aluminum plate

Tests of the Welded Joints

Preliminary Inspection of Weld Metal. Before the welded plates were cut up for strength tests they were radiographed, and cross sections of the weld joints were polished, etched and inspected at various magnifications for porosity, oxide inclusions, weld- and parent-metal cracks and other defects. In the initial stages of the work, some difficulty was encountered in producing porosity-free welds and in eliminating entrapment of the scum which sometimes formed on the surface of the weld pool. Occasionally, tungsten or tungsten-oxide inclusions were also observed in the radiographs; these occurred when the tungsten electrode got too hot and some of the molten electrode tip dropped into the weld pool, or when the electrode became contaminated with aluminum, causing a wild arc and entrainment of tungsten or tungsten oxide into the weld metal. No parent-metal cracks and very few weld cracks were observed. As the welding techniques were improved, the occurrence of cracks, excessive porosity and tungsten inclusions was eliminated. There was some evidence, on the surface of weld-metal fractures, of microporosity—very small and uniformly distributed pinholes—but this did not noticeably affect the behavior of the strength test specimens.

Strength Tests of Standard Specimens. Tension, bend and notched-bar impact specimens from the welded plates were tested at room temperature and −320° F., and a few at −420° F. The results of these tests are summarized in Table 3.

At room temperature, the strength properties of the weld metal were almost equal to those of the as-received 38 plate. The transverse tension tests of weld joints gave somewhat lower yield strengths than the all-weld-

Table 3—Strength Properties of Welds Made in 2-In. 38 Plate with 2S Filler Metal

Test specimen	*Testing temperature, ° F.*	*Yield strength, psi.*	*Ultimate tensile strength, psi.*	*Elongation 2 in., %*	*Charpy keyhole notched bar, ft.-lb.*
38 plate	+75	9,000	19,000	36	17
38 plate	−320	12,300	41,000	43	18
38 plate	−420	.....	43,000	26*	17
Weld metal†	+75	8,300	16,000	22	11
Weld metal	−320	9,600	35,600	26	12
Weld metal	−420	.....	41,000	28	12
Weld joint‡	+75	6,300	15,300	30	..
Weld joint	−320	8,400	30,000	29	..
Weld joint§	+75	6,000	16,000	33‖	..

* The room-temperature elongation of this shipment of 38 plate (which was not used in the tests at +75° F. and −320° F.) was 24%. Thus, there was no actual decrease in ductility at the −420° F. temperature.

† All-weld-metal $^1/_2$-in. round bars used in tension tests.

‡ One-half-inch round bars, transverse to weld joint, used in tension tests.

§ Full-thickness flat-bar tension specimens (2- × 1-in. cross section), weld reinforcement removed.

‖ Elongation in 8-in. gage length including weld joint.

metal tests or the parent plate tests. This is attributed to the yielding of the annealed parent plate adjacent to the weld (which was included in the gage length on which extension under load was measured), and possibly to the directional properties of the weld deposit. Using as a basis the yield strength of 3S plate in the annealed condition (0 temper, 6000 psi.), the test data indicated that the welded joints could be considered as 100% efficient in transverse tension.

The tests at −320 and −420° F. showed that neither the 3S plate nor the weld metal and weld joint suffered any loss in strength and ductility at the lower temperatures. Indeed, the tensile strength at −320° F. was double that at room temperature, with no change or even a slight increase in the yield strength and the elongation.

Some strength tests were also made on weld-joint specimens which had been subjected to about 30 cycles of cooling to −320° F. and reheating to room temperature. These specimens were tested at room temperature and at −320° F., and had the same strength properties as specimens which had not undergone the cyclic cooling.

The Charpy-bar tests indicated that the weld metal had a lower energy absorption than the wrought 3S plate, but this difference is small, and not significant except as it indicates the inherent difference in behavior of cast and cold-worked metal. There was no change in the notched-bar properties at low temperature, and all of the bars, whether wrought parent plate or weld metal, broke with ductile fractures. While these results are reported here, to the writer's knowledge there has never been a sound reason for a notched-bar test of 3S plate.

Strength Tests of Large Welded Plates. To check the observations on the test specimens cut from the welded plates, other large plates of 3S were argon-arc welded with 3S filler metal, and were bent or broken, full size, under a 2700-lb. board hammer falling from a height of about 4 ft., after having been cooled in liquid nitrogen to about −320° F. Numerous tests of this type were made, with the face or the root of the weld joint on the tension side of the bend, and with or without machined notches or simulated chisel marks and dents on the surface of the weld and in the adjacent heat-affected zone.

Many of these welded plates required several blows of the hammer to start and complete a fracture. Approximate measurements of the energy absorbed by the board hammer in bending or breaking the specimens indicated that, when the specimens were constrained to break in the weld metal, less energy was required to produce the fracture than when unwelded plates were used. This is to be expected because of the somewhat lower ductility of the 2S weld metal as compared with the 3S wrought plate. In every case, however, the fracture was a progressive and completely ductile one.

Typical 3S Aluminum Weldments

Typical all-welded 3S aluminum structures are shown in Figs. 5 to 8, inclusive. The argon-arc process was used in the fabrication of these weldments.

Figure 5 shows an aluminum unfired pressure vessel, 60 in. I. D. by 29 ft. over-all, with $1^1/_4$-in. shell, $1^1/_4$-in. heads and $^1/_2$-in. skirt.

Figure 6 shows an aluminum heat exchanger, 50 in. I. D. by 18 ft. over-all, with $^{15}/_{16}$-in. shell, 2-in. tube sheets, 2-in. shell at tube sheets, and $^3/_8$-in. head and $^1/_2$-in. skirt. There are more than 2000 aluminum tubes, $^5/_8$-in. O. D., in the vessel.

Figure 7 shows the welding of a bank of tubes for a heat exchanger. Each bank consists of tubes varying from $^3/_4$ to 10 in. in diameter. A model of an assembled heat exchanger is shown in Fig. 8.

Fig. 5 All-welded aluminum unfired pressure vessel. (Photograph, courtesy Stacey Brothers Gas Construction Co.)

THE STRENGTH OF WELD JOINTS IN HEAT-TREATABLE ALUMINUM-ALLOY PLATES

When weight saving is not a primary consideration, and the required strength of the weldment can be obtained by simply increasing the thickness of the sections, and when the optimum in weldability properties and weld-joint ductility is desired, the use of the common alloys such as 3S is indicated. However, there are applications where both high strength and light weight are desirable, and where it would be advantageous to use thinner sections because of the attendant savings in fabrication time and material. For these applications, it is necessary to consider the high-strength heat-treatable alloys such as 14S, 24S, 61S, 63S and 75S.

Fig. 6 All-welded aluminum heat exchanger. (Photograph, courtesy Stacey Brothers Gas Construction Co.)

Fig. 7 Argon-arc welding of aluminum tubes for heat exchanger. (Photograph courtesy Stacey Brothers Gas Construction Co.)

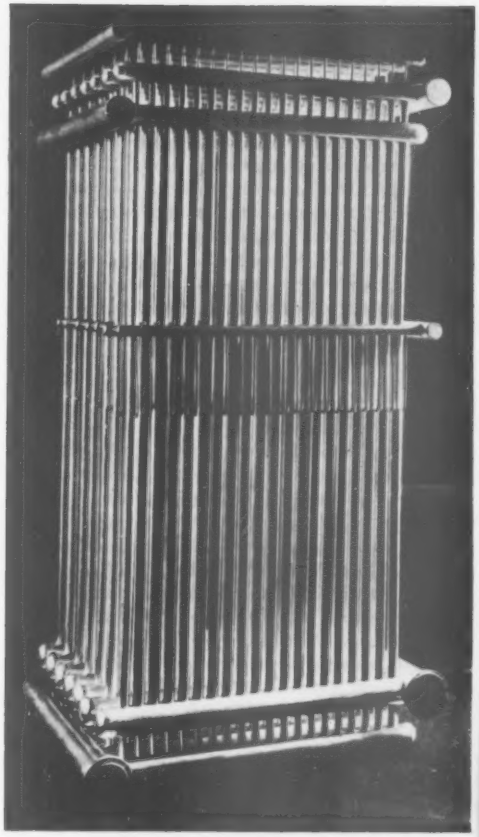

Fig. 8 Model of assembled all-welded-aluminum tubular heat exchanger. (Photograph, courtesy Stacey Brothers Gas Construction Co.)

The research at Battelle on the welding of the high-strength alloys is divided into two phases: (1) evaluation of the strength properties of weld joints made with the filler metals now available, and (2) the development of new filler alloys which will produce weld metals with higher strength and ductility, better response to the heat treatments used for the parent plates and less susceptibility to weld-metal cracking. Since the number of plate alloy compositions to be tested was necessarily limited, 24S, 61S, and 75S were chosen as representative of the heat-treatable materials.

The first phase of this work has been substantially completed, and the results of some of the tests are given below.

Preparation of Welded Plates

The procedure used in the welding of the high-strength aluminum alloy plates was substantially the same as that used for the 3S weldments previously described. However, no attempt was made to eliminate rectification of the welding current.

In addition, the preheating procedure was controlled more closely. The plate was not allowed to cool below the initial preheat temperature, nor to heat up excessively as welding progressed. It was important to maintain the minimum preheat and interpass temperature consistent with satisfactory welding, since most of the plate materials used suffer a deleterious change in strength properties if held for any length of time at temperatures much greater than 300° F.

In the welding of the high-strength plates, no particular difficulties were encountered in the manipulation of the weld pool and in securing fusion into the side walls of the joint. Radiographs and macrosections of the welded plates revealed no harmful porosity or oxide entrapment. However, weld-metal cracking was a problem. For example, it was found impossible to make good welds with 61S filler rod in 61S alloy plate; all of these welds contained numerous small cracks. Crack-free welds with 75S filler and 75S plate were made only after the clamps holding the plates to the welding table were partially loosened, and the preheat increased from 300 to 400° F.

In addition, macrosections of some of the welded joints, particularly those in 61S plate, revealed an occasional trace of eutectic melting in the heat-affected metal adjacent to the weld. Under unfavorable conditions of stressing during welding, this could result in cracking of the heat-affected parent plate. In the present tests no such cracking was observed, and possibly because of its orientation parallel to the plane of the plate, the eutectic melting had no deleterious influence on the behavior of the tension and bend specimens.

After the welded plates were radiographed, they were machined into test specimens in the as-welded condition, or after heat treatment. Two kinds of heat treatment were used: (1) aging, using the temperature and time recommended for the particular plate alloy, and (2) solution heat treatment at a high temperature, followed by a water quench and aging at a lower temperature.

Weld-Metal Strength Tests

To determine the strength of weld metals resulting from the combinations of various filler rods and alloy plates, standard $^1/_2$-in.-round tension bars were machined from the weld metal deposited in single-vee joints, as shown in Fig. 3. The results of the tension tests, which were conducted only at room temperature, are summarized in Table 4.

Welds Made with 43S Filler Metal. The welds made with 43S filler rod had approximately the same yield and tensile strengths regardless of the composition of the base plate. The ductility of the welds in 61S plate was good, somewhat lower for the 24S-T base plate, and on the low side for 75S-T plate.

No useful improvement in strength or ductility was obtained when the 43S welds were heat treated. Using the yield strength as a basis of comparison, the fully heat-treated 43S weld deposits were at most only one-third as strong as the parent plate:

Table 4—Strength of Weld Metals Deposited in High-Strength Aluminum-Alloy Plates with Various Filler Metals*

Plate	*Filler metal*	*Heat treatment after welding†*	*Yield strength, psi.*	*Ultimate tensile strength, psi.*	*Elongation 2 in. %*	*Reduction in area, %*
E61ST	(Unwelded)	As-reed.	39,000	45,000	19	42
E61ST	43S	None	11,000	25,000	17	24
E61ST	43S	STA	13,000	24,000	16	25
E61ST	71S	None	15,000	41,000	7	7
E61ST	71S	STA	41,000	57,000	5	6
E61ST	61S	‡	...	...	...	...
E24ST	(Unwelded)	As-reed.	49,000	71,000	22	27
E24ST	43S	None	14,000	31,000	11	14
E24ST	43S	STA	16,000	34,000	14	19
E24ST	71S	None	22,000	44,000	7	8
E24ST	71S	STA	38,000	54,000	6	7
E24ST	24S	None	31,000	36,000	2	3
E24ST	24S	STA	43,000	56,000	4	8
E75ST	(Unwelded)	As-reed.	73,000	84,000	14	19
E75ST	43S	None	13,000	26,000	6	10
E75ST	43S	STA	19,000	31,000	7	14
E75ST	71S	None	18,000	42,000	6	9
E75ST	71S	STA	30,000	52,000	8	9
E75ST	75S	None	§	34,000	< 1	< 1
E75ST	75S	STA	70,000	72,000	< 1	3

* Tension tests of all-weld-metal $^1/_2$-in. round bars; data shown are average of 2 or more tests.
† STA signifies full heat treatment (solution heat treat, quench and age).
‡ All joints made with 61S filler rod cracked in the weld metal during welding; no tension test data now available.
§ Both specimens tested fractured without yielding.

Relative Strength of 43S Weld Deposits

Filler metal	*Base plate*	*Yield strength of heat-treated weld metal, psi.*	*Yield strength of heat-treated base plate (T condition), psi.*	*Yield-strength ratio, weld/base*
43S	E61S	13,000	39,000	0.33
43S	E24S	16,000	49,000	0.33
43S	E75S	19,000	73,000	0.26

The conclusion may be drawn that, despite the relatively good welding characteristics and ductility of the 43S filler metal, it is not a truly satisfactory filler metal for use with the alloy plates, because the strength of the plate itself is not sufficiently utilized. However, there are probably many applications in which the combination of 61S plate and 43S filler can be applied to advantage. This is because higher joint strengths can be obtained, despite the low joint efficiency, than if 3S plate is used.

Welds Made with 71S Filler Metal. These welds were appreciably stronger than comparable welds made with 43S, but their ductility was much lower. When the 71S welds were heat treated, there was a marked increase in yield and tensile strengths, with no loss in ductility. Again using yield strength as a basis, the performance of the fully heat-treated 71S welds was as indicated in the following table:

Relative Strength of Type 71S Weld Deposits

Filler metal	*Base plate*	*Yield strength of heat-treated weld metal, psi.*	*Yield strength of heat-treated base plate (T condition), psi.*	*Yield-strength ratio, weld/base*
71S	E61S	41,000	39,000	1.05
71S	E24S	38,000	49,000	0.78
71S	E75S	30,000	73,000	0.41

The above table indicates that the 71S–61S combination results in weld metals with a strength, in the heat-treated condition, equal to that of the base plate.

There is but little experience in the use of the 71S alloy as a weld metal. If, however, the results continue to follow the present trends, it is possible that the 71S alloy may be adopted for use in the assembly of aluminum-alloy weldments. The 71S metal possesses very good welding characteristics, with the drawback of low ductility.

Welds with Filler Metal of Same Composition as Base Plate. Where it was possible to make welds with filler metal of the same composition as the base plate, the weld metal had very good strength, particularly in the heat-treated condition, but the ductilities were rather low. The data in Table 4 show that, for welds in 24S-T plate, the 24S filler had no better properties than the 71S filler. The data for welds with 75S filler indicate that, while very high yield and tensile strengths can be obtained by fully heat treating the deposit, the ductility is very low.

The present indications are that it is not practicable to use 24S, 61S and 75S alloys as filler metals in large weld joints, principally because of their susceptibility to cracking during welding. However, the research now in progress on modifications of the complex filler alloys may bring out compositions with better-balanced combinations of tensile strength and ductility, and improved welding characteristics.

Influence of Dilution on Weld-Metal Strength. When the filler metal and the base plate are of different types, the composition of the weld metal depends on the amount of filler rod required to fill the groove, and on the amount of base plate that is melted into the weld. As a rule, it is safe to assume that the mixture of filler rod and base plate is thorough, and that the weld metal is uniform in composition and strength properties throughout. In the making of welds in thick plates, however, and particularly when single-vee joints are used, there may be an unequal dilution of base metal into the weld metal. This inequality in dilution is sometimes sufficient to cause a marked difference in the strength properties of the weld metal at various locations in the joint.

An example of this is shown in Table 5, which gives the tensile strength and ductility of all-weld-metal round bars cut from the top and bottom of a single-vee joint in 24S-T plate.

When 43S filler metal was used, the strength of the weld metal at the bottom of the joint was appreciably greater than at the top. Conversely, the ductility of the bottom weld metal was less than that of the top weld metal. This difference persisted even in fully heat-treated welds.

When 24S filler metal was used in filling the groove in 24S-T plate, there was no difference in the strength properties of the weld metal at the top and the bottom of the joint.

This variation in strength properties of weld metal in

Table 5—Comparison of Strength of All-Weld-Metal Tension Bars from Top and Bottom of a Single-Vee Joint in Thick E24ST Plate

Filler metal	*Heat treatment after welding**	*Location of test bar†*	*Yield strength, psi.*	*Ultimate tensile strength, psi.*	*Elongation 2 in., %*	*Reduction in area, %*
43S	None	*t*	9,400	26,700	14	18
43S	None	*b*	18,300	34,600	7	9
43S	STA	*t*	12,000	28,900	15	23
43S	STA	*b*	20,000	38,800	12	15
24S	None	*t*	30,900	36,100	2	3
24S	None	*b*	31,400	36,300	2	3
24S	STA	*t*	43,000	55,600	4	7
24S	STA	*b*	43,300	57,000	4	8

* STA—full heat treatment (solution treatment, quench and age).

† Location of 1/2-in. round bars, as shown below:

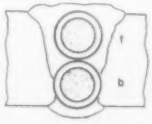

Table 5

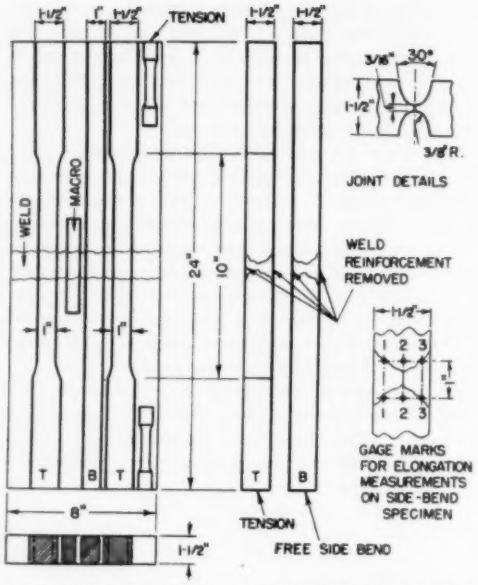

Fig. 9 Details of tension and bend specimens from double-U weld joint in thick aluminum-alloy plates

deep grooves may be of considerable importance in weldments where the magnitude of applied loads is different on the two sides of the weld joint. The variation can be eliminated, for all practical purposes, by using joint designs with grooves of equal dimensions on both sides of the plate.

Tests of Weld Joints

The strength properties of welded joints in the aluminum-alloy plates were also studied by means of full-thickness tension and side-bend specimens cut transverse to the weld joint. The details of the welded plates used for these tests are shown in Fig. 9, and typical cross sections of the multiple-bead double-U weld joints are shown in Fig. 10. In this figure, the lower section is $1^1/_2$-in. 24S-T plate welded with 24S filler, in

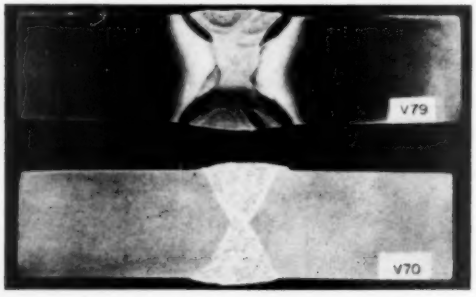

Fig. 10 Cross section of typical double-U weld joints in $1^1/_2$-in. 24S-T plate

the as-welded condition. The upper section is a companion weld, using the same materials, after solution heat treatment and aging. Note the absence of the dark heat-effect bands in the heat-treated weld.

The specimens for these tests were welded with a procedure similar to that used for the all-weld-metal specimens, except that a double-U groove joint was used. This joint design was chosen because it required less weld metal than the single-vee joint, and because it was desired to prevent the warping of the plate which tends to occur when all welding is done from one side. With the double-U joint, the effects of unequal base-metal dilution and weld-metal strength across the joint were also eliminated, but this condition had not been anticipated when the double-U design was chosen, and was not a reason for choosing it.

In addition, $^1/_2$-in.-round bar tension specimens were cut from the corners of the weld specimens, remote from the region directly affected by the welding heat, to determine the influence of the secondary heating (preheat) on the properties of the base plate.

For the tests of the E61S and E75S alloys, plates in two conditions of heat treatment—the W-temper and the T-temper—were used. The objective was to determine the possible difference in the weld-joint strength of the two sets of plates, owing to the difference in their initial conditions; and also to determine if the strength of the W-temper specimens could be improved by aging after welding. While the plate material immediately adjacent to the weld is heated to a sufficiently high temperature to cause rapid overaging and annealing regardless of the initial temper of the plate, this zone is relatively narrow. In the outer, wider part of the heat-affected zone, the temperatures incident to welding are lower, and probably the heat effect varies with the initial temper. In W-temper plate, the welding heat tends to age the outer zone to a higher strength; while in T-temper plate, the effect is to overage the zone, with a loss in strength.

If it could be demonstrated that, under proper welding conditions, W-temper plate is not seriously overaged adjacent to the weld, assemblies of this material could be used in the as-welded condition, or their strength might be improved by aging after welding. The aging treatment is considerably simpler, obviously, than the full heat treatment (solution heating, quenching and aging) which is required if the material has been overaged during welding. Another potential advantage in the use of W-temper material for weldments is that it is easier to form and bend than the harder and stronger T-temper material.

Tests of Welds in E61S Plate. The strength data for weld joints in E61S plate are given in Table 6. With one exception, all of these weld joints failed in the weld metal, or in the weld metal and along the fusion line between the weld and parent plate. For this reason, the transverse tensile strength of the weld joints was about the same as the ultimate tensile strength of the all-weld-metal specimens listed in Table 4. The highest joint efficiencies were obtained with the fully heat-

Table 6—Strength and Ductility of Double-U Weld Joints in 1½-In. E61S Plate

				Transverse tension test§				Free-bend test‖	
Plate*	Filler metal	Welding temperature, °F.†	Heat treatment after welding‡	Ultimate tensile strength, psi.	Joint efficiency, %¶	Location of fracture**	Reduction in area at fracture, %	Location of fracture**	Elongation across weld, 1-in. gage, %
E61SW	...	...	...	35,000	..	P	46	P	72
E61SW	43S	300	None	23,000	51	WF	15	WF	17
E61SW	43S	300	A	24,600	55	WF	6	W	15
E61ST	...	...	...	45,000	..	P	38	P	70
E61ST	43S	300	None	23,600	52	WF	21	W	20
E61ST	43S	300	A	25,300	56	WF	11	W	13
E61ST	43S	300	STA	42,600	95	WF	6	W	11
E61ST	71S	300	None	26,300	58	W	7	W	10
E61ST	71S	300	STA	46,300	100	P	34	W	8
E61ST	61S	††	...	...	..	..	..	..	..

* Strength of unwelded plate given for comparison; see Table 2.
† Preheat temperature and approximate average temperature of entire plate during welding.
‡ A—aged 8 hr. at 350° F. STA—solution treated 8 hr. at 970° F.; water quenched; aged 8 hr. at 350° F.
§ Full-thickness, flat-bar tension specimens, see Fig. 3. Values shown are averages for 2 specimens.
‖ Full-thickness, side-bend specimens, see Fig. 3. Values shown are for single specimens.
¶ Based on tensile strength of as-received E61ST plate.
** P—plate; W—weld metal; F—fusion line.
†† Joints made with 61S filler rod cracked in weld during welding.

treated specimens—95% for the 43S weld and 100% for the 71S weld.

The ductility measurements obtained from the free-bend tests show the same trend as did the elongation and reduction in area measurements on all-weld-metal specimens. No yield strengths are reported for the transverse tension tests, because of the unequal yielding in the various zones—heat-affected metal, unaffected metal and weld metal—included in the reduced-section gage length.

The fully heat-treated weld made with 71S filler metal in E61S-T plate is the first instance, in this investigation, of a weld joint which was stronger than the parent high-strength alloy plate. However, the free-bend tests and all-weld-metal tests show that this weld metal has a relatively low ductility.

Tests of Welds in E24S-T Plate. The strength data for weld joints in E24S-T plate are given in Table 7. Here again, all specimens failed in the weld metal, and the strength of the welds made with the various filler metals was about the same as observed in the all-weld-metal tension tests. The ductility of the welds in 24S-T plate was lower than that of welds with similar filler metal in the 61S plate.

Tests of Weld Joints in E75S Plate. Table 8 gives the strength data for weld joints in E75S plate. In these welds, there was a greater tendency for the fracture to occur in, or partially in, the fusion line between weld and base plate, and the tensile strengths of the transverse tension specimens were usually slightly lower than that of companion all-weld-metal specimens. This suggests some metallurgical condition in the metal along the fusion line which makes it weaker than the heart of the weld metal.

While it was possible to produce heat-treated weld joints, using 75S filler metal in 75S plate, with a tensile strength of about 70,000 psi. and a joint efficiency of about 85%, the ductility of the weld metal was so low that this type of weld may be considered unsatisfactory for most engineering applications.

Tests of Weld Joints in W-Temper Plates. The data in Tables 6 and 8 for W-temper plates of E61S and

Table 7—Strength and Ductility of Double-U Weld Joints in 1½-In. E24ST Plate

				Transverse tension test				Free-bend test**	
Plate*	Filler metal	Welding temperature, °F.†	Heat treatment after welding‡	Ultimate tensile strength, psi.	Joint efficiency, %‖	Location of fracture¶	Reduction in area at fracture, %	Location of fracture¶	Elongation across weld, 1-in. gage, %
E24ST	...	...	...	70,000	..	P	18	P	31
E24ST	43S	300	None	26,200	37	W	4	WF	7
E24ST	43S	300	A	26,400	38	W	3	W	6
E24ST	43S	300	STA	36,000	51	W	6	W	8
E24ST	71S	300	None	38,200	55	W	4	W	5
E24ST	71S	300	STA	50,800	73	WF	4	WF	6
E24ST	24S	300	None	32,700	47	W	3	W	3
E24ST	24S	300	A	29,200	42	W	2	W	5
E24ST	24S	300	STA	55,700	80	WF	4	W	6

* Strength of unwelded plate given for comparison; see Table 2.
† Preheat temperature and approximate average temperature of entire plate during welding.
‡ A—aged 8 hr. at 375° F. STA—solution treated 8 hr. at 920° F.; water quenched; aged at room temperature.
§ Full-thickness, flat-bar tension specimens, see Fig. 3. Values shown are averages for 2 specimens.
‖ Based on tensile strength of as-received E24ST plate.
¶ P—plate; W—weld metal; F—fusion line.
** Full-thickness, side-bend specimens, see Fig. 3. Values shown are for single specimens.

Table 8—Strength and Ductility of Double-U Weld Joints in 1½-In. E75S Plate

				Transverse tension test§				Free-bend test**	
Plate*	Filler metal	Welding temperature, °F.†	Heat treatment after welding‡	Ultimate tensile strength, psi.	Joint efficiency, %‖	Location of fracture¶	Reduction in area at fracture, %	Location of fracture¶	Elongation across weld, 1-in. gage, %
E75SW	...	...	...	78,000	..	P	12	P	18
E75SW	43S	300	None	20,000	24	F	<1	FP	2
E75SW	43S	300	A	20,300	25	WF	<1	WF	3
E75SW	43S	300	STA	41,700	51	WF	3	WF	3
E75SW	75S	400	None	23,000	28	WF	<1	W	<1
E75SW	75S	400	A	21,500	26	W	<1	WF	2
E75SW	75S	400	STA	72,300	88	W	1	WF	4
E75ST	...	...	...	82,000	..	P	12	P	24
E75ST	43S	300	None	21,200	26	WF	1	F	4
E75ST	43S	300	A	25,200	31	WF	2	WF	3
E75ST	43S	300	STA	40,400	49	WF	2	WF	2
E75ST	71S	300	None	32,400	40	WF	2	WF	2
E75ST	71S	300	STA	43,400	53	W	4	WF	2
E75ST	75S	400	None	23,800	29	WFP	<1	W	2
E75ST	75S	400	A	22,900	28	W	<1	W	2
E75ST	75S	400	STA	68,900	84	W	<1	W	4

* Strength of unwelded plate given for comparison, see Table 2.
† Preheat temperature and approximate average temperature of entire plate during welding.
‡ A—aged 24 hours at 250° F. STA—solution treated 8 hours at 920 F; water quenched; aged 24 hours at 250 F.
§ Full-thickness flat-bar tension specimens, see Figure 3. Values shown are averages for 2 specimens.
‖ Based on tensile strength of as-received E75ST plate.
¶ P—plate; W—weld metal; F—fusion line.
** Full-thickness side-bend specimens, see Figure 3. Values shown are for single specimens.

E75S alloys show that the specimens aged after welding were no stronger than those tested in the as-welded condition. While the aging treatment did in fact increase the strength of the base metal, there was no such response in the weld metal. Only the complete heat-treatment cycle of solution treatment, quench and age, produced a worth-while improvement in strength properties.

These data do not lead to the conclusion that the idea of using W-temper plates has no merit. What is now lacking is a weld metal which will either respond to the simple aging treatment, or which will have the necessary strength and ductility in the as-welded condition. With such weld metals, the parent plate would be called upon to do more work under load, and it would quite probably be possible to increase the strength of a W-temper weldment, at the weld and in the body of the assembly, by the simple procedure of low-temperature aging.

In considering the feasibility of improving weld-metal properties by aging treatments, an important factor is the welding procedure used. With almost all present procedures, weld joints in thick aluminum plates are filled bead by bead, layer by layer, and the heat of each weld bead has an aging effect on the weld metal previously deposited. Consequently, the weld metal may be subjected to progressive overaging, and in this state its strength properties cannot be improved by a postweld aging treatment—the full heat-treatment cycle is required. The data for aged and fully heat-treated specimens, in Tables 6, 7 and 8, support this view. It appears that one of the necessary attributes of weld-metal compositions which gain strength by aging after welding will be a sluggish response to short-time heating, so that the overaging effect during welding will be small.

Influence of Secondary Heating During Welding on Strength Properties of the Alloy Aluminum-Alloy Plates. Since the preheat temperatures generally used in aluminum welding are of the same order as the optimum aging temperatures for the high-strength aluminum alloys, it is necessary to consider the possible influence of the preheat on the properties of the material, even in regions remote from the welding area. Obviously, when a weldment is fully heat treated after welding, the effects of the initial heating during welding are effaced. The problem is of importance principally in those cases where a weldment is to be used in the as-welded condition, or after aging only.

In most of the tests reported here, the failures were in the weld metal, and no data were obtained on the possible deleterious influence of the welding heat on the parent plate immediately adjacent to the weld joint. Some information, however, was obtained on the influence of secondary heating (preheat) by measuring the strength properties of ½-in.-round bar tension specimens cut from the corner of the weld plate farthest from the weld joint (see Fig. 9). Specimens were taken from plates in the as-welded condition, whose only "heat treatment" was the 2- to 3-hr. period at the preheat temperature, and from plates which were either aged or fully heat treated after welding. The test data are given in Table 9.

E61S-W Plate: The influence of secondary heating was to increase the yield and ultimate tensile strengths of the base material, with very little change in ductility (compare Tests 1 and 2). Plate material subjected to the 300° F. heating period and then aged for 8 hr. at 350° F. (Test 3) had the strength properties of a fully heat-treated plate (Test 4).

E61S-T: Since E61S-T plate is already in the aged condition (aging treatment 350° F. for 8 hr.), the 2- to

3-hr. period at about 300° F. did not affect the strength properties (compare Tests 4 and 5). Subsequent aging at 350° F., or a full heat treatment, likewise caused no change in the strength properties (Tests 6 and 7).

E24S-T Plate: The E24S-T plate used in these tests was aged at room temperature to obtain the strength properties shown by Test 8. The 300° F. welding preheat (Test 9) produced no significant change in strength properties, but when a similar plate was subsequently aged at 375° F. for 8 hr., there was an increase in yield strength and a loss in elongation and ductility (Test 10). The recommended aging temperature for 24S-T is room temperature, although the 375° F. treatment is sometimes used where higher yield strengths are desired.

The E24S-T subjected to 300° F. preheat and then fully heat treated (Test 11) had the same strength properties as the original plate material.

E75S-W: The recommended aging treatment for 75S is 250° F. for 24 hr., and temperatures much in excess of 250° F. are likely to produce some change in the mechanical properties. Comparison of Tests 12 and 13 shows that there was a slight change in strength properties owing to the 2-hr. period at 300° F. during welding. The material aged after welding (Test 14) showed a marked increase in yield strength and some loss in elongation, while the plate fully heat treated after welding (Test 15) had strength properties similar to those of the 75S plate received in the fully heat-treated condition (Test 19).

In the welding of the E75S plate with 75S filler rod, a preheat temperature of 400° F. was used. This temperature was sufficiently high to produce, during the 2- to 3-hr. welding period, a marked loss in yield and tensile strengths, with a drop in elongation but some increase in reduction of area (Test 16). This indicated that the 400° F. temperature was sufficient to cause an overaging of the W-temper material. When a similar plate welded at 400° F. was aged at the recommended temperature (250° F. for 24 hr.), the improvement in strength properties which normally accompanies the aging treatment was not obtained, because the plate had already been overaged during the 400° F. welding period (Test 17).

When the plate which had been preheated at 400° F. was fully heat treated (Test 18), the resulting strength properties were comparable to those of E75S-T material (Test 19).

E75S-T Plate: This is material in a fully heat-treated and aged condition, and no change in strength properties was produced by a 2-hr. period at 300° F. (compare Tests 19 and 20). A subsequent aging period of 8 hr. at 275° F. (Test 21), and full heat treatment (Test 22), likewise produced no change in strength properties.

When a preheat temperature of 400° F. was used, there was a marked decrease in yield and tensile strengths of the plate (Test 23), and aging after welding was of no avail because the plate material was now in an overaged condition (Test 24). However, when the plate initially heated at 400° F. during welding was fully reheat treated (Test 25), the resulting strength properties were the same as for the original E75S-T plate.

Table 9—Influence of Secondary Heating During Welding, and Heat Treatment After Welding, on the Strength Properties of the Base Plate in Regions Remote from the Weld Area*

Test	*Plate*	*Welding temperature, ° F.†*	*Heat treatment after welding‡*	*Yield strength, psi.*	*Ultimate tensile strength psi.*	*Elongation 2 in., %*	*Reduction in area, %*
1	E61SW	...	...	21,400	35,600	28	46
2	E61SW	300	None	30,000	42,100	22	43
3	E61SW	300	A	40,400	47,400	17	39
4	E61ST	...	...	39,100	45,200	19	42
5	E61ST	300	None	39,600	45,300	18	42
6	E61ST	300	A	40,100	45,800	18	42
7	E61ST	300	STA	40,400	45,400	18	40
8	E24ST	...	...	49,100	70,900	22	27
9	E24ST	300	None	45,400	68,300	22	27
10	E24ST	300	A	57,700	68,800	12	23
11	E24ST	300	STA	45,000	68,500	24	29
12	E75SW	...	...	56,800	79,600	16	21
13	E75SW	300	None	62,900	74,500	14	27
14	E75SW	300	A	67,000	78,000	12	22
15	E75SW	300	STA	72,500	83,200	16	23
16	E75SW	400	None	44,800	59,700	11	30
17	E75SW	400	A	45,000	58,500	11	28
18	E75SW	400	STA	74,200	85,000	15	26
19	E75ST	...	...	73,300	83,600	14	19
20	E75ST	300	None	73,500	81,900	12	19
21	E75ST	300	A	72,500	81,200	13	21
22	E75ST	300	STA	71,300	80,500	13	17
23	E75ST	400	None	49,600	61,600	9	22
24	E75ST	400	A	45,300	58,700	11	34
25	E75ST	400	STA	73,600	84,400	17	29

* See Fig. 3.
† Preheat temperature and approximate average temperature of entire plate during welding.
‡ For heat-treatment details, see Tables 6, 7 and 8.

Effect of Welding Heat on Corrosion Resistance of Base Plate

Since the above investigations were concerned primarily with the strength of welded joints, the possible effect of welding on the corrosion resistance of the plate materials was not considered. The corrosion resistance of some of the alloys, particularly 24S and 75S, is greatly influenced by their heat treatment, and by the heat incident to welding operations. In any application of these alloys in welded structures which are to be exposed to corrosive media, the matter of proper heat treatment after welding, and of surface protection by painting, should be considered, and tests made to determine the corrosion-resisting properties of the weldment.

CONCLUSION

The researches described above demonstrate the practicability of welding thick aluminum plates into useful engineering structures. The tests show that, for the aluminum alloy 3S, welding methods and filler metals are now available which will produce weld joints with strength and ductility approaching those of the base metal; and furthermore, that these strength properties do not change, but even improve, at the low temperatures which obtain in the operation of equipment such as that for oxygen manufacture.

The results of the investigations also show that at least some of the heat-treatable aluminum alloys can now be welded in thick sections, with weld-joint strengths far greater than those obtainable with the common alloys, 2S and 3S. However, with the techniques and filler metals now available, the welding of the heat-treatable alloys is still attended to an undesirable degree by the hazard of weld-metal or parent-metal cracking during welding. Except at the lower strength levels, the ductility of the welds is quite low for most engineering applications. There is also the problem of the influence of the welding heat on the properties of the parent plate, which will become more important as the strength properties of the weld metal are improved.

The indications, at least for the time being, are that weldments made of thick plates of the high-strength aluminum alloys are practicable if the design is based on "as-welded" strength properties. There are several reasons for this limitation. First, the filler metals now recommended (43S and, possibly, 71S) produce welds which do not increase in strength if aged after welding. Consequently, there is not much advantage in aging the weldment, except, in certain alloys, to obtain an improvement in corrosion characteristics. Second, full heat treatment does not improve the strength properties of the weld metals, or increases only the yield and tensile strengths, with the ductility remaining at an undesirably low level. Therefore, the efficiency of the welded joints in a structure is not usefully improved by subjecting the structure to a full heat treatment after welding. Third, the solution heat treatment and quenching of aluminum-alloy weldments, especially large and complex ones, is a difficult and delicate procedure, because aluminum has very low strength at the temperatures required for solution treatment, and because it is necessary to maintain very good control of the temperatures, furnace atmospheres and quenching rates.

Research on the above and related problems is proceeding on an increasing scale in many fabrication plants and laboratories. There are very promising developments in new filler-metal compositions. The low-temperature strength of welded joints in the heat-treatable alloys is being determined. Equipment for aluminum welding, including torches, transformers and auxiliary apparatus, is being improved. Methods for mechanizing the argon-arc welding process, such as those which have been so successful in thin-gage applications, are being investigated for the welding of thick aluminum plates.

New and different methods of welding aluminum are being studied and applied. These range from welding at room temperature (no heat applied to the work), flash welding and submerged-melt welding to methods in which arc welding is done with bare aluminum electrodes in shielding atmospheres. Research on the last-named process, Aircomatic, at the Airco Research Laboratories and at Battelle, is in advanced stages. This process shows great promise for many applications, since it involves no chemical fluxing, and makes possible manual welding in all positions, and automatic welding at rates considerably greater than those obtainable with the methods now commonly used.

The results of this widespread research have already been applied in the fabrication of many large aluminum weldments, and there are encouraging indications that at least some of the more exacting desires of design engineers and fabricators will ultimately be realized.

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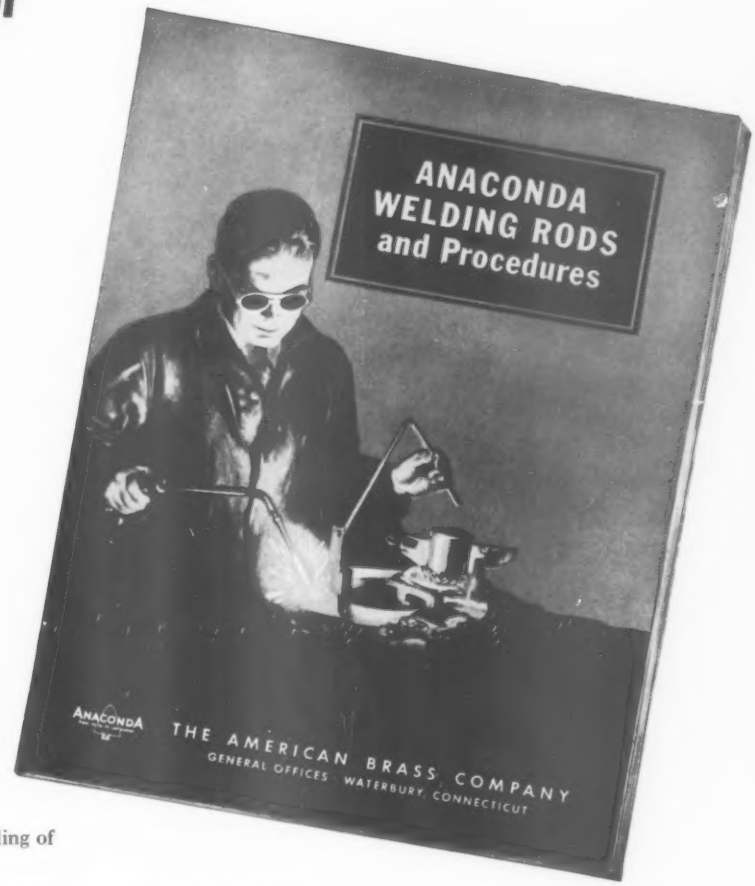

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